FINAL REPORT

ASTER YELLOWS CONTROL FOR ORGANIC HERBS AND SPICES

19980159

November 2000

Prepared by: Saskatchewan Herb and Spice Association

AGRI-FOOD INNOVATION FUND

Canada

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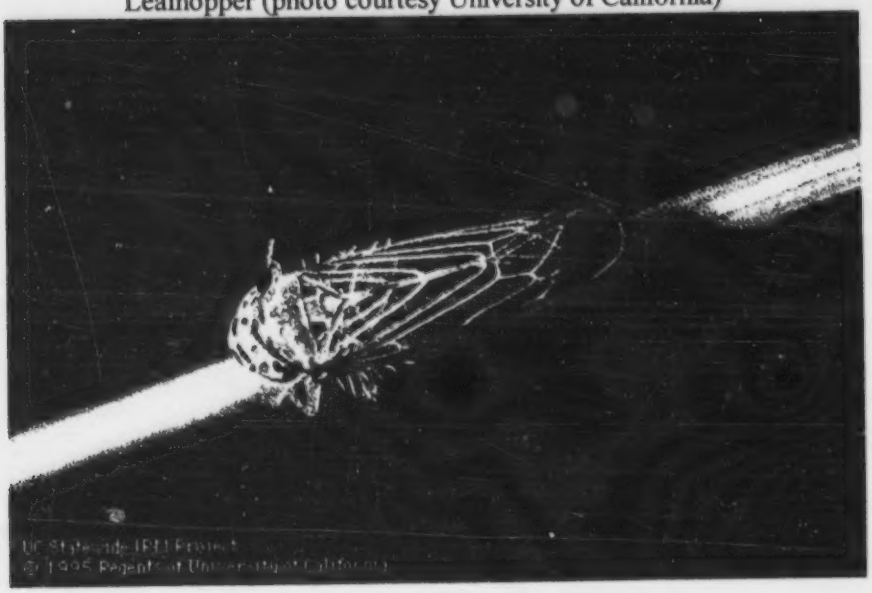
Final Report
Project # 98000159

Aster Yellows Control for Organic Herbs and Spices

Saskatchewan Herb and Spice Association
Connie Kehler

November 2000

Leafhopper (photo courtesy University of California)



AGRI-FOOD INNOVATION

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PREFACE

In the past years interest and development in the herb and spice industry has been expanding rapidly. Also within this time frame, prairie producers have found that their profit from traditional agriculture diminishing and thus were looking for ways to diversify. With the expanding herbal markets and diverse spice markets, several of these producers choose to look at herb and spice production.

It was commonly and mistakenly thought that herb and spice crops were somewhat immune to diseases. Once the crops were developed on a larger field scale and in a mono-culture fashion, producers found that they were as susceptible to disease as any other crop they produced.

The Saskatchewan Herb and Spice Association along with Ag Canada and Sask. Ag and Food have tried to ensure the success of this farm diversification through education, networking and research. When disease became an issue that threatened viable production in the herb and spice industry, steps were taken to help resolve the problem. Research such as the enclosed on Aster Yellows and an additional project on Disease in Spice Crops, have gone a long ways in addressing these concerns.

The enclosed research results focuses on organic solutions for Aster Yellows disease. The reason for this focus is that most herbal production is organic whether certified or not, due to the demands of the buyers and the public. Even buyers that claim to not need organic raw material rarely tolerate any use of pesticides or herbicides.

This project has been a joint project funded by the Canada Saskatchewan Agrifood Innovation Fund, Saskatchewan Herb and Spice Association, Agriculture Canada, Canada Saskatchewan Irrigation Diversification Centre and Alberta Agriculture, Food and Rural Development.

It has been a pleasure working with the principals. Everyone in the project put in more than requested of them for the good of the project. Joint projects such as this have a mutual benefit to all parties and help the industry as a whole.

Connie Kehler
Vice President SHSA

*Lit search provided early in project.

SUMMARY

Aster yellows can severely limit organic production of some herbs and spices in Saskatchewan. Organic insecticides tend to falter in the field under typical weather conditions and in regions where the reservoir of leafhoppers is substantial. In Saskatchewan, leafhopper populations increase quickly and remain relatively high all summer, probably due to the wide-spread presence of alternate host plants. When the rate of infected leafhoppers is high, more plants will be exposed to aster yellows and subsequently act as disease sources. Infected perennial weeds and annual crops like canola act as reservoirs of aster yellows and would influence the level of disease in the next season.

PROJECT RECOMMENDATIONS

Sanitation is key:

- If possible, grow herbs and spices in isolation from other crops. Keep a bare soil barrier around plots free of alternate host plants
- Control leafhoppers as best one can in the area outside of the crop as well
- Know the symptoms of aster yellows and remove any infected plants from the area as soon as possible.

Organic insecticides can help:

- Apply weekly; if possible apply only when rain is not forecast.
- In plant bioassays, pyrethrin controlled leafhoppers significantly better than neem extract, rotenone and diatomaceous earth (in that order)
- In insect bioassays, pyrethrin controlled leafhoppers significantly better than neem extract, diatomaceous earth and rotenone (in that order)
- In field trials, less disease was found in plots treated with pyrethrin
- Powdered rotenone is very difficult to get into solution and to apply; it is not recommended for field application.

Host plants vary in susceptibility:

- Annual species may be less damaged than perennials due to their shorter life cycle
- As a perennial, *E. augustifolia* is significantly less susceptible than fever few and valerian

TECHNICAL REPORT

A. Background:

Micro-organisms called phytoplasmas (mycoplasmas or mycoplasma-like organisms) are the main cause for yellows disease in a wide range of native and cultivated plant species. The yellows disease is transmitted primarily by phloem feeding leaf hoppers (See Photograph on front cover). The incidence of aster yellows disease appears to be increasing on the prairies in recent years.

Leaf hoppers infestations can result from local resident populations or from migrations on favourable winds from other places. Migratory populations often have a higher damage potential because they tend to arrive in a host crop earlier in the season than local populations. Suction traps have been successfully used to monitor migrations of insect pests in Saskatchewan. A small network of suction traps would provide an early warning of leaf hopper migrations plus they would also provide growers with and indication of leaf hopper population increase in the different growing areas.

Monitoring programs for leaf hopper infestations is an essential component for successful control. The options for insect and disease control in organic production requires validation under Saskatchewan field conditions. This project will address these two requirements.

B. Objectives:

1.) Compile a compile a comprehensive review of issues surrounding aster yellows.
2.) Monitor the migration patterns of insect vectors (leaf hopper) in Saskatchewan.
3.) Establish plots of selected herbs and spices, validate the efficacy of selected organic insecticides under farm field conditions.
4.) Monitor the development of aster yellows in research plots.

C. Project Activities and Achievements

Activity 1: Compile a compile a comprehensive review of issues surrounding aster yellows.

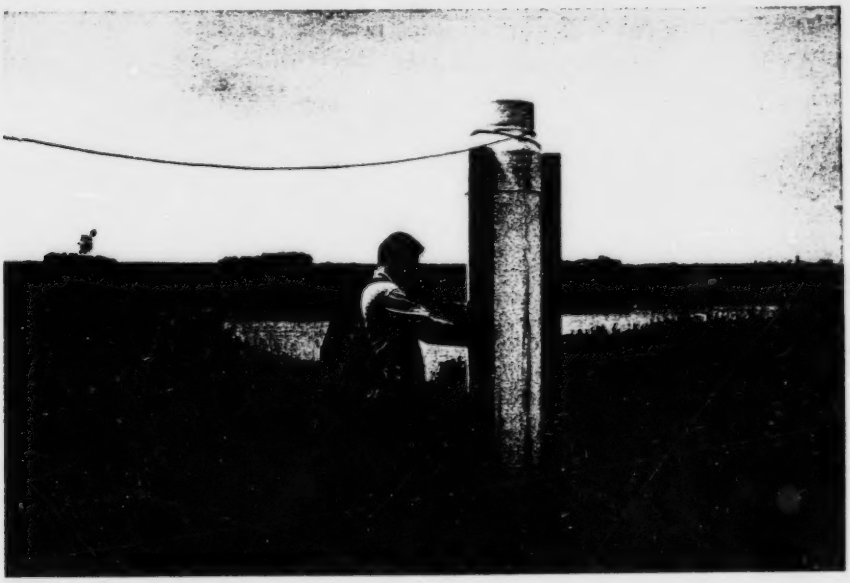
Achievement:

Two reports (enclosed) have been prepared by the consultant reviewing the issues surrounding aster yellows. These include: (i) a comprehensive discussion of host plants susceptible to phytoplasma, the geographic distribution of aster yellows, a list of vectors responsible for transmitting disease and the geographical distribution of leafhoppers; and (ii) a comprehensive literature review and reference list.

Activity 2: Monitor the migration patterns of insect vectors (leaf hopper) in Saskatchewan.

Achievement:

Suction traps were erected and deployed in 1999 and 2000 at three locations in Saskatchewan (Consul, Aberdeen and Dundurn) and insect migrations were monitored on a weekly basis (See Photograph #1). Wind trajectory models, developed by Environment Canada, were used to determine when migrations of leaf hoppers might be occurring. To monitor local populations of leaf hoppers, sticky cards (n=20 per site) were installed within each of the research plots and assessed weekly (See Photograph #2).



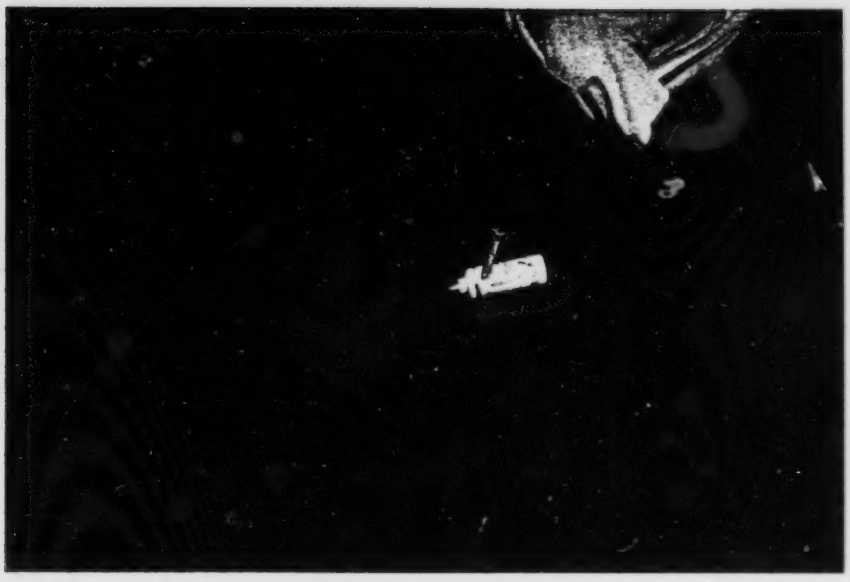
Photograph 1: Summer student changing collection jar in suction trap designed to capture migratory insects such as leaf hoppers.

Photograph 2: Yellow sticky cards designed to capture local populations of leafhoppers that transmit phytoplasma.

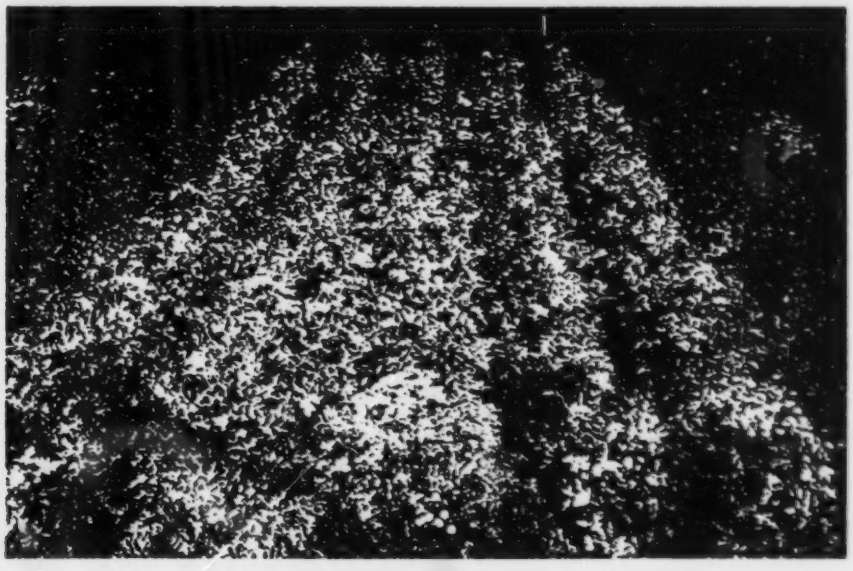
Activity 3: Establish plots of selected herbs and spices, validate the efficacy of selected organic insecticides under farm field conditions

Achievement:

Four selected herb and spice crops [echinacea (*E. angustifolia*), feverfew, valerian, annual caraway, and coriander] were established at four locations (Moose Jaw, Dundurn, Aberdeen and Prince Albert). Organic insecticides (rotenone, pyrethrum with fatty acid soaps, diatomaceous earth in 1999; plus azadyractin = *NEEMIX* ™ in 2000) were applied at recommended rates to field plots on a weekly/bi-weekly basis to control of leaf hoppers that spread aster yellows. (See Photographs #3 and #4).



Photograph 3: Biologist applying diatomaceous earth dust to valerian plants to control leaf hoppers.



Photograph 4: Coriander plots after being treated with diatomaceous earth dust to control leaf hoppers.

Activity 4: Monitor the development of aster yellows in research plots

Achievement: Aster yellows (AY) disease incidence was recorded during plot inspections in July, 1999, and twice in 2000 (July, September) in field plots which where established at Aberdeen, Moose Jaw, and Dundurn in 1999. In 1999 the plots were sprayed with Pyrethrin, Rotenone, diatomaceous earth (DE); NEEMIX was added in 2000. The efficacy of these treatments was determined by the incidence of AY on caraway, coriander, echinacea, feverfew, and valerian

Additional Activity – 2000: Conduct bioassay of organic insecticides in the laboratory

A. Plant Spray Test

The methods used in the plant bioassay :

- Five Treatments: rotenone, pyrethrum, neem extract, diatomaceous earth and check
- Five replicates: five canola plants in pots for each treatment. Canola was pre-flowering.
- Leafhoppers: collected from field using sweep net

The organic insecticides were mixed to recommended strength. Plants were sprayed or dusted to get good coverage on the canola leaves. The plants were air-dryed for 15 minutes and were placed inside screened cages. Ten leafhoppers were added to each cage. The cages were placed inside a growth cabinet set at 20 degrees C and 16:8 light:dark. The number of alive and dead leafhoppers were counted after 5 days.

B. Insect Spray Test

The methods used in the insect bioassay:

- Five Treatments: rotenone, pyrethrum, neem extract, diatomaceous earth and check
- Aster leafhoppers were collected with a sweep net and kept in the laboratory until used.
- Ten leafhoppers were placed in 500ml margarine containers fitted with a plastic cone top
- Five replicates of five treatments

The organic insecticides were mixed to recommended strength. Neem and pyrethrum were applied with a spray bottle. The rotenone was applied with a squirt bottle and the diatomaceous earth was applied directly into the containers. In all cases treatments were applied directly into the assay chambers containing the leafhoppers so as to completely moisten or coat the filter paper on the bottom. A canola leaf was added to each cage daily. Containers were placed in a growth cabinet set at 20 degrees C and with a light-dark regime of 16:8 light dark. Counts of dead and alive leafhoppers were made 24, 48, 96 and 120 hours after treatment.

D. Reults and Conclusions

Activity 1: Compile a compile a comprehensive review of issues surrounding aster yellows

Results: Copy of the review is enclosed as a separate publication

Activity 2: Monitor the migration patterns of insect vectors (leafhopper) in Saskatchewan.

Results: Three suction traps were erected and placed into service by Agriculture Canada in early May (Consul, Aberdeen and Dundurn)to provide an early warning of leaf hopper migrations. The insects were sampled on a weekly basis beginning in mid-May. Wind trajectory models, developed by Environment Canada, were used to determine when migrations of leafhoppers might be occurring.

1999

Suction trap sampling indicated that migratory leaf hoppers arrived as early as May 31 in Moose Jaw, June 16 in Consul and July 21 in Aberdeen. The trap counts are presented in Appendix A.

To monitor local populations of leafhoppers, sticky cards (n=20 per site) were installed within each of the plots in late June. Results indicate that leafhoppers were present in the plots by mid June in relatively low numbers. The most northern site (Prince Albert) had the lowest population density in mid-June (mean density of 6 individuals per card). The most southern site (Moose Jaw) had the highest population density (14 individuals per card). By the third week in July, mean density increased to 16 at Prince Albert and to 50 individuals per card at Moose Jaw. The counts of leafhoppers collected on sticky cards are also presented in Appendix C.

2000

Suction trap sampling indicated that migratory leafhoppers arrived as early as May 23 in Consul and May 29 in Moose Jaw and Aberdeen. The trap counts to date are presented in Appendix B.

To monitor local populations of leafhoppers, sticky cards (n=20 per site) were installed within each of the plots in late June. At the new site, Conservation Learning Centre (Prince Albert) , the sticky cards were not put in until the last week of July because of the 2000 planting. Results indicate that leafhoppers were present in all plots before the sticky cards were put out. Leafhopper numbers were high early in the season this year. At Prince Albert, the highest numbers of leafhoppers occurred in late July. At all other locations, the numbers increased until early August. The counts of leafhoppers collected on sticky cards are also presented in Appendix D.

Activity 3: Establish plots of selected herbs and spices, validate the efficacy of selected organic insecticides under farm field conditions

Results:

1999

The crops echinacea (*E. angustifolia*), feverfew, valerian, annual caraway, and coriander were established at four locations (Moose Jaw, Dundurn, Aberdeen and Prince Albert) to determine the occurrence and distribution of aster yellows, and to evaluate the efficiency of various organic insecticides. Coriander and caraway were seeded in early May, the remaining three crops were established as transplants in late May.

Leaf hopper density appears to be different between crop types. In general, the lowest numbers are found on echnicaea followed by valerian, caraway, feverfew and coriander, respectively. This may not reflect the inherent attractiveness of the respective crops but rather the amount of plant biomass of each of the crops. Echnicea is the least established (no crop canopy) of the five crops while the biomass of the coriander is the greatest.

Three organic insecticides were selected for evaluation at all four sites. They are rotenone, pyrethrum with fatty acid soaps, and diatomaceous earth. In addition, garlic oil has been included as a fourth treatment at the Dundurn site. Insecticide treatments began in mid-June and have continued on a weekly/bi-weekly basis depending on precipitation events. The potential efficacy of the control treatments may have been severely hampered by the timing of precipitation events. At most sites, rainfall has followed insecticide treatments within 48 hours, and in some cases, within 24 hours. Excessive rainfall (200% - 240% of normal in June and July) has likely reduced the efficacy of insecticide treatments and created a more favourable environment for disease development. As a result, population densities of leafhoppers were still increasing at most sites as of the third week in July. the dates and type of treatments implemented are presented in Appendix C.

2000

The crops echinacea (*E. angustifolia*), feverfew, valerian, annual caraway, and coriander were established at four locations (Moose Jaw, Dundurn, Aberdeen and Prince Albert) to determine the occurrence and distribution of aster yellows, and to evaluate the efficiency of various organic insecticides. Coriander and caraway were seeded in early May, the remaining three crops were established as transplants in late May. Our collaborator at Prince Albert withdrew from the study in 1999. As a result, an alternate collaborator (Conservation Learning Centre) was identified and plots reestablished in the Prince Albert area for 2000. Valerian transplants were not available for the new site at Prince Albert in 2000.

Leaf hopper density appears to be different between crop types. In general, the lowest numbers are found on echincaea followed by valerian, feverfew, caraway, and coriander, respectively. This may not reflect the inherent attractiveness of the respective crops but rather the amount of plant biomass of each of the crops. Echnicea is the least established (no crop canopy) of the five crops while the biomass of the coriander is the greatest. At Dundurn, the valerian had very high numbers at the start of the season at the time that the biomass peaked. The diseased valerian plants were removed after the assessment by the pathologist. As a result, leafhopper numbers decreased sharply in that plot.

Three organic insecticides were selected for evaluation at all four sites. They were rotenone, pyrethrum with fatty acid soaps, and diatomaceous earth. An additional product, neem extract, was evaluated in 2000. We received a research permit for the botanical insecticide, azadyractin (*NEEMIX* ™) in July, allowing us to add this treatment to the list. Insecticide treatments began in late-June and have continued on a weekly/bi-weekly basis depending on precipitation events. The potential efficacy of the control treatments may have been severely hampered by the timing of precipitation events. At most sites, rainfall has followed insecticide treatments within 48 hours, and in some cases, within 24 hours. Excessive rainfall in June and July has reduced the efficacy of insecticide treatments and created a more favourable environment for disease development. As a result, population densities of leafhoppers were still increasing at most sites into mid-August. The dates and type of treatments implemented are presented in Appendix D.

Activity 4: Monitor the development of aster yellows in research plots

Results:

Feverfew:
Seedlings were transplanted into plots at Saskatoon and no AY was found on the plants. The occurrence of AY was lower at Aberdeen than at Moose Jaw. Pyrethrin spray reduced the disease incidence more than the other treatments at Aberdeen. However, an additional examination is needed to confirm these observations.

Valerian:
More than 50% of the valerian plants were killed either by low temperatures or by root rot diseases at Aberdeen and Moose Jaw. This situation makes it difficult to accurately determine AY incidence among treatments. Typical symptoms of AY such as phyllody occurred at every location. In most locations, the incidence of AY is higher than last year. A suggestion has been made to remove the above-ground portions of the plants to facilitate the next examination in September.

Echinacea angustifolia:
The crop still had the lowest disease incidence (<10%) among the tested crops at all locations, especially in Saskatoon. There was no significant difference among the treatments.

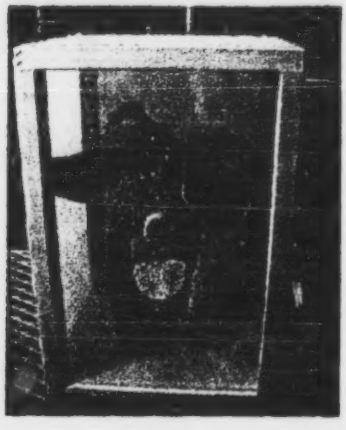
Caraway and Coriander:
New crops of caraway and coriander were established in all locations in the summer of 2000. There was no AY apparent at any of the locations in July. The fields will be re-examined for AY in early September.

In summary:
The incidence of AY was higher at all locations in 2000 than in 1999 for all tested crops. Echinacea crops showed the lowest incidence of aster yellows occurred at all test locations. The efficacy of Pyrethrin, Rotenone, DE and garlic oil to control AY needs to be confirmed late in the growing season of this year.

The dates and diseased plant counts in the different treatments are presented in Appendix E and F.

Additional Activity – 2000: Conduct bioassay of organic insecticides in the laboratory

The efficacy of the four botanical insecticides was evaluated in 2000 in the laboratory, under more controlled conditions to assess their efficacy on the plant and on the insect (Photograph 5).



Photograph 5. Cage with canola plant used to assess the efficacy of the organic insecticide treatements at controlling leafhoppers

Plant Spray Test: Results indicated that in plant bioassays, pyrethrin (95% control) controlled leafhoppers significantly better than neem extract (22%), rotenone (19%) and diatomaceous earth (9%) within 24 hours (Figure 1). The data are presented in Appendix G.

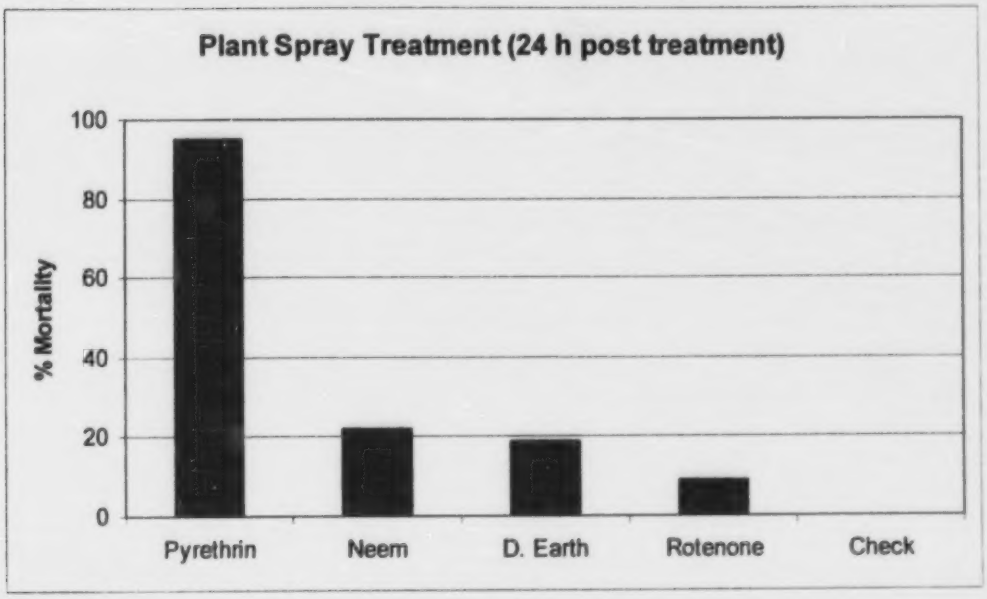


Figure 1. The mortality (%) of leafhoppers when placed on caged canola plants which had been treated with four different insecticides (24 hours post treatment).

Insect Spray Test: Results indicated that in insect bioassays, pyrethrin (100% control) controlled leafhoppers significantly better than neem extract (64%), diatomaceous earth (42%) and rotenone (30%) within 24 hours (Figure 2). The data are presented in Appendix G.

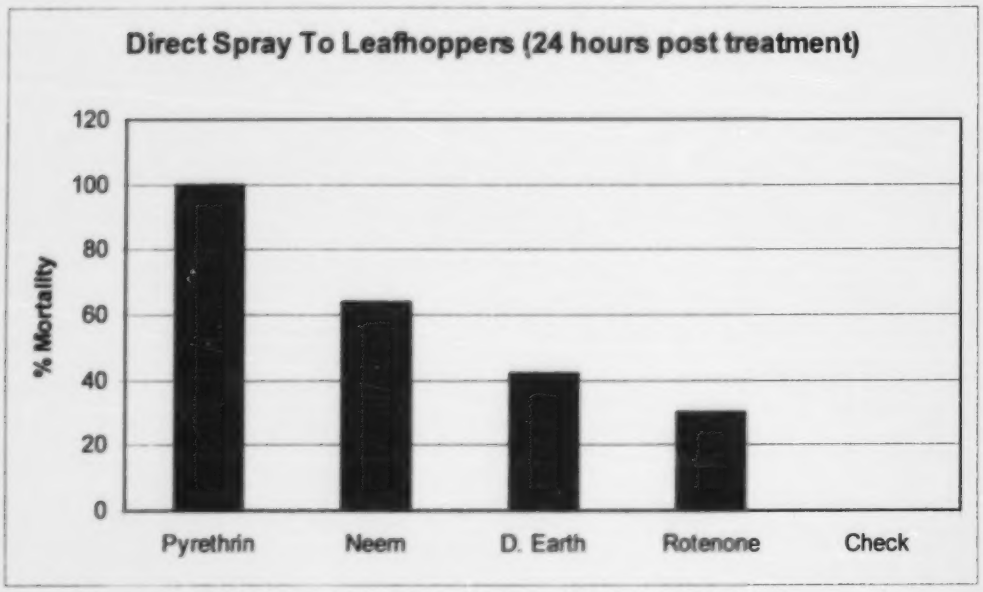


Figure 2. The mortality (%) of leafhoppers when sprayed directly with four different insecticides (24 hours post treatment).

Changes to Research Program in 2000:

1.) An alternate study site was established at Prince Albert because of the withdrawal from the study of a collaborator in 1999.

2.) There was several instance of severe winter kill of feverfew. In these instances, the plots were replanted.

3.) A research permit was obtained for neem extract (azadyractin) in July. Treatments began soon thereafter.

4.) The efficacy of the four botanical insecticides was also evaluated in the laboratory, under more controlled conditions to determine whether direct contact with the insects was essential for control.

Indications for further development:
Recommend further investigation:

- Evaluation of organic insecticides other than pyrethrin, neem extract, rotenone or diatomaceous earth is required.
- Studies to determine the optimum isolation protocols required to reduce leafhopper influx from surrounding area (local migration) is required
- Studies to determine the level of infectivity of leafhoppers that are endemic to Saskatchewan would be valuable information
- As assessment of the status of natural enemies (parasitoids, disease) of leafhoppers would be of benefit to the development of IPM.
- Studies to determine if leafhoppers are able to overwinter in Saskatchewan is required.
- An IPM strategy (cultural, biological and chemical controls and host plant resistance) needs to be developed to manage leafhoppers that transmit aster yellows.

Information on performance indicators:

n/a

(c) Personnel

Activity 1.	Celine Burns	consultant	$5,000

Activities 2 and 3. Neil Nichols (AAFC-Saskatoon) 5 months/year

Activity 4. Kan fa Chang

(d) Equipment

n/a

(e) Project Photos

The following photographs are available upon request:

- Suction trap to monitor migratory leafhoppers
- Sticky cards with leafhopper specimens
- Student treating plots with organic insecticides
- Feverfew plots treated with diatomaceous earth
- Cages and plants used in lab evaluations of the insecticides

(f) Innovation Fund Acknowledgement

The Innovation Fund was acknowledged in each of the presentations listed below.

(g) Project Public Information Materials

1. An informational article on the project titled *Aster Yellows Control for Organic Production of Herbs and Spices* (prepared by M. Braun and O. Olfert, Agriculture and Agri-Food Canada) was distributed to members of the Saskatchewan Herb and Spice Association in July 1999.
2. M. Braun made a presentation at the Aberdeen site on leafhoppers to approximately 60 visitors during the International Herb /Conference on July 25.
3. O. Olfert co-hosted a workshop on management of aster yellows disease at Herbfest-2000 at Outlook on July 23.
4. M. Braun made a presentation on leafhoppers to approximately 50 visitors during the Open House at the Conservation Learning Centre (Prince Albert) on August 3.

(i) Expense Statement

see attached

APPENDIX A. Data Collected on Leaf Hopper Migrations in Saskatchewan, 1999

Moose Jaw
Suction Trap

Jar in Date	Jar out Date	# of A. Leafhoppers
24-May	31-May	0
31-May	7-Jun	2
7-Jun	14-Jun	4
14-Jun	21-Jun	4
21-Jun	28-Jun	0
28-Jun	5-Jul	0
5-Jul	12-Jul	0
12-Jul	19-Jul	1
19-Jul	26-Jul	13
26-Jul	2-Aug	152
2-Aug	9-Aug	113
9-Aug	16-Aug	85
16-Aug	23-Aug	95
23-Aug	30-Aug	no sample because suction trap was plugged
30-Aug	6-Sep	49

Aberdeen
Suction Trap

Jar in Date	Jar out Date	# of A. Leafhoppers
21-May	27-May	0
27-May	2-Jun	0
2-Jun	9-Jun	0
9-Jun	16-Jun	0
16-Jun	23-Jun	0
Suction trap faulty up to this point. Operating normally on June 23.		
23-Jun	29-Jun	0
29-Jun	7-Jul	0
7-Jul	14-Jul	0
14-Jul	21-Jul	No sample because trap was clogged.
21-Jul	28-Jul	2
28-Jul	4-Aug	1
4-Aug	11-Aug	0
11-Aug	18-Aug	0
18-Aug	25-Aug	8
25-Aug	31-Aug	8

Consul
Suction Trap

Jar in Date	Jar out Date	# of A. Leafhoppers
19-May	26-May	0
26-May	2-Jun	0
2-Jun	10-Jun	0
10-Jun	16-Jun	1
16-Jun	23-Jun	3
23-Jun	30-Jun	0
30-Jun	7-Jul	0
7-Jul	14-Jul	5
14-Jul	21-Jul	0
21-Jul	28-Jul	7
28-Jul	4-Aug	21
4-Aug	11-Aug	21
11-Aug	18-Aug	16
18-Aug	25-Aug	16
25-Aug	1-Sep	12
1-Sep	8-Sep	7
8-Sep	15-Sep	0

APPENDIX B. Data Collected on Leaf Hopper Migrations in Saskatchewan, 2000

Moose Jaw
Suction Trap

Jar in Date	Jar out Date	Leaf hoppers
22-May	29-May	4
29-May	5-Jun	3
5-Jun	19-Jun	2
19-Jun	26-Jun	9
26-Jun	3-Jul	24
3-Jul	10-Jul	37
10-Jul	17-Jul	90
17-Jul	24-Jul	52
24-Jul	1-Aug	49
1-Aug	16-Aug	49
16-Aug	22-Aug	3
22-Aug	29-Aug	4
29-Aug	06-Sept	28
06-Sept	18-Sept	16

Consul
Suction Trap

Jar in Date	Jar out Date	Leafhoppers
12-May	17-May	0
17-May	23-May	1
23-May	31-May	2
31-May	7-Jun	2
7-Jun	14-Jun	4
14-Jun	21-Jun	3
21-Jun	29-Jun	5
29-Jun	5-Jul	9
5-Jul	13-Jul	18
13-Jul	19-Jul	12
19-Jul	26-Jul	19
26-Jul	2-Aug	38
2-Aug	8-Aug	71
8-Aug	16-Aug	56
16-Aug	23-Aug	54
23-Aug	30-Aug	13
30-Aug	7-Sept	13
07-Sept	13-Sept	16
13-Sept	20-Sept	65
20-Sept	27-Sept	10
27-Sept	05-Oct	6

Aberdeen
Suction Trap

Jar in Date	Jar out Date	Leafhoppers
08-May	15-May	0
15-May	23-May	0
23-May	29-May	4
29-May	05-Jun	4
05-Jun	12-Jun	2
12-Jun	19-Jun	0
19-Jun	26-Jun	0
26-Jun	5-Jul	0
05-Jul	17-Jul	2
17-Jul	26-Jul	0
26-Jul	03-Aug	15
03-Aug	10-Aug	12
10-Aug	17-Aug	2
17-Aug	24-Aug	2
24-Aug	31-Aug	18
31-Aug	15-Sept	1

APPENDIX C. Data Collected on Leaf Hoppers and Chemical Control in Saskatchewan, 1999

Prince Albert
Sticky Cards

DATES

Crop	Treatment	28/6-5/7	5/7-12/7	12/7-19/7	19/7-26/7	26/7-1/8	1/8-16/8	16/8-23/8
Echinacea	Rotenone	4-bn	5	18	19	0	16	13
	Control 1	4-b	3	14	12	6-d	2	12
	Pyrethrin	3-bn	6	8	3	3	4	18
	D.E.	4-bn	13	15	53	23	6	31
	Control 2	9-b	31	22	85	28	15	35
Feverfew	Control1	2-b	7	17	63	27	67	77
	D.E.	2-bn	0-d	36	69	17	90	50
	Pyrethrin	8-bn	10	15	85	25	95	63
	Control 2	8-b	12	40	59	12	25	56
	Rotenone	5-bn	19	24	89	15	48	37
Valerian	Pyrethrin	5-bn	10	31	61	13	29	51
	D.E.	11-bn	5	8	a	9	46	54
	Control 1	3-b	0-d	17	25	3	29	55
	Control 2	5-b	5	48	55	1	36	64
	Rotenone	4-bn	10	20	79	13	24	36
Caraway	Control 1	8-b	6	7	16	2	85	110
	Pyrethrin	1-bn	0-d	14	14	4	57	135
	Control 2	2-b	5	1	27	7	79	86
	Rotenone	3-bn	6	3	a	8	35	140
	D.E.	7-bn	2	15	a	10	54	130
Coriander	D.E.	30-n	3	10	a	6	55	101
	Control 1	5-b	5	a	17	2	43	61
	Rotenone	1-bn	10	2	a	8	42	116
	Control 2	8-b	0-d	11	13	5	24	73
	Pyrethrin	5-bn	4	7	11	2	5	75

five without labels

Jo was sick so no spray and no cards for the 8th

b=one side only

n=not sprayed

d=excessive dirt

a=card absent

unknown a=35

unknown b=30

unknown c=11

unknown d=24

Aberdeen

Sticky Cards

DATES

Crop	Treatment	28/6-5/7	5/7-12/7	12/7-19/7	19/7-27/7	27/7-3/8	3/8-10/8	10/8-17/8	17/8-23/8
Echinacea	Pyrethrin	2-dn	15	7	4	4	0	3	11
	Control 1	0-d	5	10	5	5	1	3	7
	D.E	2-dn	8	9	10	2	1	2	1
	Control 2	2-d	4	3	9	1	1	2	8
	Rotenone	0-dn	6	8	10	2	2	1	2
Feverfew	Control 1	34	15	117	40	24	12	4	14
	Control 2	25	24	98	30	20	7	3	14
	Rotenone	7-dn	10	70	35	16	9	5	7
	D.E	21-n	24	74	29	4	12	8	28
	Pyrethrin	22-n	54	75	23	2	5	1	15
Valerian	Pyrethrin	4-n	19	18	20	21	2	10	20
	Control 1	0	2	23	14	12	1	5	22
	Control 2	3	7	9	7	17	3	5	26
	Rotenone	1-n	1	5	9	15	0	16	10
	D.E	2-n	2	12	19	16	8	5	20
Coriander	D.E	3-dn	22	61	83	51	34	9	26
	Rotenone	2-dn	42	15	75	48	19	5	43
	Pyrethrin	29-n	15	32	54	31	12	3	45
	Control 1	9	80	27	42	30	24	12	51
	Control 2	17	31	38	63	43	22	14	29
Caraway	Pyrethrin	19-wn	39-n	18	28	25	14	38	156
	Rotenone	40-wn	46-n	17	53	69	25	19	107
	Control 1	24-w	22	4	36	25	8	43	137
	D.E	10-wn	8-n	8	18	23	35	22	164
	Control 2	32-w	10	21	38	17	22	33	166

rained after application

w=weeds

n=not sprayed

Dundurn

DATES

Sticky Cards

Crop	Treatment	29/6-5/7	5/7-12/7	12/7-19/7	19/7-26/7	26/7-2/8	2/8-9/8	9/8-16/8	16/8-23/8
Echinace	Control	0	3	0	0	1	2	2	3
	Rotenone	4-n	3-n	1	1	0	3	5	0
	D.E.	4-n	3-n	0	2	0	6	2	2
	Garlic	6-n	2-n	0	2	1	5	3	3
	Pyrethrin	1-n	2-n	2	11	1	3	1	0
Feverfew	Garlic	10-n	11-n	8	36	7	18	29	4
	Rotenone	13-n	9	15	37	17	13	25	12
	Pyrethrin	18-n	36	19	25	19	6	20	7
	D.E.	5-n	18	16	34	20	12	16	5
	Control	16	11	4	34	9	13	14	7
Valerian	Garlic	0-n	1-n	3	3	2	4	12	8
	Control	4	4	3	6	5	8	26	15
	Pyrethrin	12-n	4-n	7	27	9	9	25	11
	D.E.	14-n	5-n	12	11	14	14	38	23
	Rotenone	1-n	6-n	1	11	12	47	10	16
Caraway	Pyrethrin	4-n	10-n	6	27	35	7	26	13
	Garlic	14-n	9-n	10	32	28	37	22	11
	Rotenone	35-n	21-n	18	50	7	16	5	6
	D.E.	39-n	28-n	30	37	39	11	3	19
	Control	25	14	18	52	45	39	6	25
Coriander	Control	5	15	21	29	0	11	5	14
	Rotenone	30-n	9-n	19	25	1	5	6	2
	D.E.	47-n	13-n	19	39	3	4	5	2
	Pyrethrin	33-n	20-n	11	22	6	6	9	6
	Garlic	17-n	13-n	9	25	14	3	9	10

n=not sprayed

Moose Jaw
Sticky Cards

DATES

Crop	Treatment	28/6-5/7	5/7-12/7	12/7-19/7	19/7-26/7	26/7-2/8	2/8-9/8	9/8-16/8	16/8-23/8
Echinacea	D.E.	14-n	3-n	14	12	67	51	39	31
	Control 1	3	3	10	7	41	36	27	34
	Pyrethrin	5-n	10-n	12	16	38	21	12	23
	Control 2	5	2	11	7	25	11	18	23
	Rotenone	5-n	8-n	12	6	32	50	21	33
Feverfew	Rotenone	29-n	56-n	119	117	194	205	66	75
	Control 1	29	78	69	104	188	200	92	184
	Control 2	36	72	110	98	174	293	68	117
	Pyrethrin	33-n	79-n	126	103	205	155	7	128
	D.E.	22-n	63-n	124	106	144	121	64	141
Valerian	D.E.	0-n	5-n	31	a	95	91	36	81
	Control 1	0-c	6	20	18	94	131	79	131
	Control 2	2	7	28	17	111	119	21	76
	Pyrethrin	6-n	9-n	31	19	146	120	32	81
	Rotenone	3-n	5-n	47	25	128	94	17	73
Caraway	Control 1	0-c	2	15	5	93	147	77	94
	Control 2	12	11	25	23	165	158	88	119
	Rotenone	4-n	11-n	34	47	81	111	35	124
	Pyrethrin	4-n	4-n	21	36	164	181	31	83
	D.E.	17-n	12-n	33	43	177	a	57	120
Coriander	Control 1	3	2	68	2	214	255	32	59
	Rotenone	3-n	6	70	19	152	146	29	59
	Pyrethrin	3-n	6-n	71	44	215	208	4	57
	D.E.	2-n	2-n	35	7	195	130	20	55
	Control 2	10	19	105	66	165	113	25	65

c=broken card
n=not sprayed
a=absent card

APPENDIX D. Data Collected on Leaf Hoppers and Chemical Control in Saskatchewan, 2000

Aberdeen
Sticky Traps 2000

Crop	Treatment	12/6-19/6	19/6-26/6	26/6-4/7	4/7-10/7	10/7-18/7	18/7-26/7	26/7-3/8	3/8-9/8	9/8-17/8	17/8-23/8	23/8-31/8	31/8-7/9
Echinacea	Pyrethrin	2	18	16	63	33	17	35	24	19	7	22	7
	Control 1	15	27	27	64	46	12	25	23	14	18	17	5
	D.E	10	35	21	33	37	36	37	13	7	7	13	4
	Control 2	19	31	32	25	36	23	24	27	11	9	7	1
	Rotenone	26	31	15	50	40	63	16	14	6	7	25	7
Feverfew	Cohtrol 1	12	29	51	79	80	64	46	97	49	28	24	13
	Control 2	19	58	31	152	62	65	61	37	27	1	13	7
	Rotenone	22	72	55	98	69	58	38	41	31	13	18	3
	D.E	35	40	37	106	69	55	34	21	38	10	12	4
	Pyrethrin	22	30	29	72	56	40	53	42	26	9	29	N/a
Valerian	Pyrethrin	1	2	4	7	3	19	22	33	25	12	17	8
	Control 1	3	4	8	0	0	9	15	40	19	17	5	9
	Control 2	1	0	3	1	1	13	15	26	15	4	6	9
	Rotenone	1	0	1	3	1	15	25	23	20	15	18	10
	D.E	1	0	3	5	1	10	21	33	19	12	44	4
Coriander	D.E				8	12	21	144	121	78	20	25	6
	Rotenone				9	8	51	235	126	61	21	25	7
	Pyrethrin				6	18	20	189	140	68	10	19	2
	Control 1				11	12	23	143	121	72	9	16	0
	Control 2				12	13	29	173	73	58	4	22	5
Caraway	Pyrethrin				8	15	4	75	76	10	5	27	0
	Rotenone				16	7	8	64	64	14	8	18	2
	Control 1				12	9	4	52	23	7	8	18	0
	D.E				9	10	3	44	31	5	9	31	2
	Control 2				5	13	6	21	14	2	2	22	2

spraying began on June 28

neem sprayed on Aug. 9

Conservation Farm

Sticky Traps 2000

Crop	Treatment	7/20-7/27	7/27-8/3	8/3-8/9	8/9-8/16	8/16-8/23	8/23-8/31	8/31-9/7
Caraway	DE	306	273	122	71	85	43	8
	Rotenone	410	309	319	105	77	42	6
	Control	398	332	366	141	83	38	5
	Neem	384	250	365	87	87	44	5
	Pyrethrin	339	228	276	88	81	34	8
Echinacea	Control	34	67	42	26	11	44	5
	Pyrethrin	45	45	67	18	19	42	10
	DE	31	50	67	14	11	29	4
	Rotenone	36	49	50	32	7	58	2
	Neem	33	36	39	36	10	43	5
Feverfew	DE	34	37	61	65	41	159	35
	Pyrethrin	42	55	115	87	86	133	35
	Neem	29	43	101	70	48	148	18
	Rotenone	30	38	72	81	43	21	20
	Control	59	145	67	91	47	121	27
Coriander	DE	145	60	195	38	60	41	9
	Rotenone	246	272	103	65	93	27	14
	Neem	339	225	80	40	105	11	10
	Control	198	219	117	77	62	21	9
	Pyrethrin	301	229	126	77	75	11	11

Sprayed Neem Aug 16

spraying began July 13, 2000

Moose Jaw
Sticky Traps 2000

Crop	Treatment	6/26-7/3	7/3-7/10	7/10-7/17	7/17-7/24	7/24-8/1	8/1-8/9	8/9-8/16	8/16-8/23	8/23-8/30	8/30-9/5	9/5-9/18
Echinacea	D.E.	21	16	19	11	40	69	44	37	1	27	9
	Control 1	21	21	10	10	29	42	29	57	44	20	22
	Pyrethrin	12	21	20	14	36	33	38	39	12	11	13
	Control 2	24	4	24	8	32	56	11	42	30	27	12
	Rotenone	11	15	21	12	26	39	89	41	39	36	30
Feverfew	Rotenone		21	14	15	30	7	42	19	40	14	9
	Control 1		16	24	28	28	13	20	15	13	12	3
	Control 2	5	22	20	18	31	106	64	21	19	11	10
	Pyrethrin	15	16	13	18	14	30	45	25	6	2	1
	D.E.	32	14	5	2	3	36	52	21	39	30	20
Valerian	D.E.	15	14	19	11	13	31	47	31	7	15	19
	Control 1	8	7	12	1	7	40	42	19	39	22	10
	Control 2	3	5	6	16	21	29	36	26	33	11	15
	Pyrethrin	1	4	1	0	7	23	23	30	29	18	16
	Rotenone	4	11	23	14	33	51	19	24	9	65	19
Caraway	Control 1	31	12	6	12	7	34	24	23	7	17	7
	Control 2	49	48	15	33	16	23	19	30	21	18	7
	Rotenone	42	4	1	15	3	13	15	9	23	10	9
	Pyrethrin	37	7	0	19	0	7	4	30	26	5	9
	D.E.	66	14	5	19	1	9	15	33	13	18	7
Coriander	Control 1	26	30	11	6	3	7	22	31	15	67	34
	Rotenone		7	15	13	13	30	41	37	22	42	18
	Pyrethrin	9	8	12	11	3	15	19	40	7	16	10
	D.E.	13	15	4	12	0	39	44	24	44	71	25
	Control 2	29	0	7	14	12	7	20	29	51	36	2

spraying began on July 1,2000
Sprayed Neem on Aug 16

Dundurn
Sticky Traps 2000

Crop	Treatment	6/1-6/10	6/11-6/17	6/18-6/24	6/25-7/1	7/2-7/9	7/9-7/15	7/16-7/22	7/23-7/30	7/30-8/6	8/6-8/12	8/12-8/27
Echinacea	Control	15	2	2	3	4	17	9	6	88	19	55
	Rotenone	3	3	2	4	8	23	7	13	96	11	60
	D.E.	10	5	5	6	3	30	10	16	70	16	33
	Garlic	4	2	2	1	10	29	4	9	78	5	38
	Pyrethrin	0	2	3	0	11	25	4	15	37	21	36
Feverfew	Garlic	7	1	4	12	15	4	17	26	117	39	141
	Rotenone	0	6	9	15	26	14	12	31	135	49	165
	Pyrethrin	4	11	26	12	25	32	17	27	100	42	172
	D.E.	0	7	12	18	10	21	10	45	151	49	214
	Control	4	2	13	10	15	9	6	21	39	21	130
Valerian	Garlic	129	9	8	5	12	13	10	12	7	6	2
	Control	157	3	0	6	6	22	15	11	10	8	17
	Pyrethrin	159	4	5	1	9	15	6	21	45	12	23
	D.E.	152	25	7	11	26	36	54	35	79	23	11
	Rotenone	165	16	4	13	53	25	24	34	23	30	0
Caraway	Pyrethrin			16	22	39	19	52	73	127	39	116
	Garlic			13	25	103	24	63	86	121	30	128
	Rotenone			14	24	92	58	75	130	50	90	119
	D.E.			14	12	73	54	73	155	129	66	116
	Control			9	18	40	56	45	124	89	91	61
Coriander	Control			4	23	166	62	116	91	72	26	51
	Rotenone			5	36	91	145	132	90	134	32	76
	D.E.			6	28	145	114	79	89	160	52	99
	Pyrethrin			7	16	74	90	75	93	216	24	84
	Garlic			12	18	24	81	47	33	170	20	30

Spraying began
Jun 30, 2000
neem sprayed on
Aug 9, 2000

APPENDIX E. Yellow Asters Disease Evaluation in Herbs and Spices - 1999

Table 1. Effect of treatments on the control of phytoplasma diseases occurring on caraway at different locations of Saskatchewan in 1999.

Treatment (Plot no.)	Location	No. plants infected per row										Avg. Disease incidence (%)
		Row number										
		1	2	3	4	5	6	7	8	9	10	
(1) Pyrethrin	Aberdeen	2	1	1	2	0	1	0	0	1	-	
(2) Rotenone		0	2	1	1	1	0	1	0	0	-	
(3) Control 1		0	0	0	1	1	0	0	0	0	-	
(4) D.E.		0	1	0	1	0	0	0	0	0	-	
(5) Control 2		0	1	0	0	0	0	0	0	0	-	
(1) Control 1	Moose Jaw	2	3	2	4	0	4	1	4	3	5	
(2) Control 2		3	3	5	2	1	5	2	2	6	4	
(3) Rotenone		10	7	3	2	5	2	0	1	2	5	
(4) Pyrethrin		6	3	6	6	2	6	6	1	7	4	
(5) D.E.		10	3	5	2	4	4	7	1	5	6	

(1) Control 1	Prince Albert	2	2	1	5	1	2	-	-	-	-	
(2) Pyrethrin		2	0	2	1	1	1	-	-	-	-	
(3) Control 2		2	1	2	6	2	1	-	-	-	-	
(4) Rotenone		3	4	1	2	2	0	-	-	-	-	
(5) D.E.		1	1	4	7	3	4	-	-	-	-	
(1) Pyrethrin	Saskatoon	3	2	0	0	5	2	1	4	-	-	
(2) Garlic oil		2	3	3	2	4	3	3	5	-	-	
(3) Rotenone		0	2	2	3	2	4	2	2	-	-	
(4) D.E.		1	5	1	1	4	1	0	2	-	-	
(5) Control		2	2	2	1	2	7	3	4	-	-	

Table 2. Effect of treatments on the control of phytoplasma diseases occurring on coriander at different locations of Saskatchewan in 1999.

Treatment (Plot no.)	Location	No. plants infected per row										Avg. Disease incidence (%)
		Row number										
		1	2	3	4	5	6	7	8	9	10	
(1) D.E.	Aberdeen	0	0	2	1	1	1	0	0	0	0	
(2) Rotenone		0	0	1	1	0	1	0	1	0	0	
(3) Pyrethrin		1	1	0	0	0	0	1	1	0	1	
(4) Control 1		1	0	1	1	0	1	0	0	1	0	
(5) Control 2		1	0	0	0	1	1	0	0	0	0	
(1) Control 1	Moose Jaw	0	0	0	0	1	0	0	1	2	0	
(2) Rotenone		6	1	0	1	2	2	0	2	2	1	
(3) Pyrethrin		2	1	1	1	0	0	2	0	1	0	
(4) D.E.		3	2	0	2	2	0	2	1	1	2	
(5) Control 2		1	0	0	0	2	1	2	1	0	2	
(1) D.E.	Prince Albert	5	8	5	5	4	6	-	-	-	-	

(2) Control 1		5	5	3	5	5	6	-	-	-	-	
(3) Rotenone		6	4	2	3	5	3	-	-	-	-	
(4) Control 2		4	3	2	5	2	5	-	-	-	-	
(5) Pyrethrin		2	1	3	2	0	2	-	-	-	-	
(1) Control	Saskatoon	0	0	0	1	1	0	1	0	-	-	
(2) Rotenone		1	0	0	0	0	0	0	0	-	-	
(3) D.E.		0	0	0	0	0	0	0	0	-	-	
(4) Pyrethrin		0	0	0	0	0	0	0	0	-	-	
(5) Garlic oil		0	0	0	0	0	0	0	0	-	-	

Table 3. Effect of treatments on the control of phytoplasma diseases occurring on *Echinacea angustifolia* at different locations of Saskatchewan in 1999.

Treatment (Plot no.)	Location	No. plants infected per row								Avg. disease incidence (%)
		Row number								
		1	2	3	4	5	6	7	8	
(1) Pyrethrin	Aberdeen	0	0	0	0	0	0	-	-	0
(2) Control 1		0	0	0	0	0	0	-	-	0
(3) D.E.		0	0	0	0	0	0	-	-	0
(4) Control 2		0	0	0	0	0	0	-	-	0
(5) Rotenone		0	0	0	0	0	0	-	-	0
(1) D.E.	Moose Jaw	0	0	0	0	1	0	0	0	0.6
(2) Control 1		0	0	0	0	0	0	0	0	0
(3) Pyrethrin		0	0	0	0	0	0	0	0	0
(4) Control 2		0	0	0	0	1	0	0	0	0.6
(5) Rotenone		0	0	0	0	0	0	0	0	0
(1) Rotenone	Prince Albert	0	0	0	0	0	0	-	-	0

(2) Control 1		0	0	1	0	0	1	-	-	1.7
(3) Pyrethrin		1	2	0	1	0	1	-	-	4.2
(4) D.E.		0	1	1	1	1	0	-	-	3.3
(5) Control 2		0	0	0	0	1	0	-	-	0.8
(1) Control	Saskatoon	0	0	0	0	1	-	-	-	1
(2) Rotenone		0	0	0	0	0	-	-	-	0
(3) D.E.		0	0	0	0	0	-	-	-	0
(4) Garlic oil		0	0	0	0	0	-	-	-	0
(5) Pyrethrin		0	0	0	0	0	-	-	-	0

There are 20 plants/row and 5 rows per plot (treatment). However, there are 8 row per plot (treatment) in the trial at Moose Jaw.

Table 4. Effect of treatments on the control of phytoplasma diseases occurring on feverfew at different locations of Saskatchewan in 1999.

Treatment (Plot no.)	Location	No. plants infected/row						Avg. disease incidence (%)
		Row number						
		1	2	3	4	5	6	
(1) Control 1	Aberdeen	5	1	4	5	4	1	33.3
(2) Control 2		5	3	3	5	3	2	35.0
(3) Rotenone		3	3	4	4	3	3	33.3
(4) D.E.		3	4	3	1	3	2	26.7
(5) Pyrethrin		2	3	3	4	2	4	30.0
(1) Rotenone	Moose Jaw	5	5	5	3	5	5	46.7
(2) Control 1		6	3	4	4	4	5	43.3
(3) Control 2		6	3	3	2	2	2	30.0
(4) Pyrethrin		7	7	3	6	5	3	51.7
(5) D.E.		4	5	4	2	3	2	33.3
(1) Control 1	Prince Albert	6	4	5	6	7	8	60.0

(2) D.E.		6	6	8	4	5	6	58.3
(3) Pyrethrin		5	7	9	5	6	5	61.7
(4) Control 2		7	6	6	4	4	6	55.0
(5) Rotenone		8	6	6	3	4	7	56.7
(1) Garlic oil	Saskatoon	3	2	1	4	5	-	25.0
(2) Rotenone		4	5	3	4	4	-	33.3
(3) Pyrethrin		2	2	1	4	5	-	23.3
(4) D.E.		3	4	2	5	5	-	31.7
(5) Control		3	4	3	5	3	-	30.0

There are 10 plants/row and 6 rows per plot (treatment). However, there are 12 plants/row with 5 row per plot (treatment) in the trial at Saskatoon.

Table 5. Effect of treatments on the control of phytoplasma diseases occurring on valerian at different locations of Saskatchewan in 19

Treatment (Plot no.)	Location	No. plants infected per row						Avg. disease incidence (%)
		Row number						
		1	2	3	4	5	6	
(1) Pyrethrin	Aberdeen	2	3	1	0	3	3	20.0
(2) Control 1		1	2	2	0	0	1	10.0
(3) Control 2		4	1	1	1	0	1	13.3
(4) Rotenone		1	2	1	0	2	0	10.0
(5) D.E.		1	2	3	2	3	1	20.0
(1) D.E.	Moose Jaw	8	7	4	8	4	6	61.7
(2) Control 1		6	6	4	4	4	2	43.3
(3) Control 2		6	4	4	4	4	1	38.3
(4) Pyrethrin		10	6	6	5	3	2	53.3
(5) Rotenone		5	3	3	2	1	3	28.3
(1) Pyrethrin	Prince Albert	6	10	8	8	6	10	80.0
(2) D.E.		8	10	9	9	9	7	86.7
(3) Control 1		10	10	10	7	8	10	91.7
(4) Control 2		9	8	7	8	8	8	80.0
(5) Rotenone		10	6	9	9	6	8	80.0
(1) Garlic oil	Saskatoon	0	1	1	0	1	-	5.0
(2) Control		1	0	1	3	1	-	10.0
(3) Pyrethrin		4	1	2	6	2	-	25.0
(4) D.E.		4	4	6	6	6	-	43.3
(5) Rotenone		8	7	2	4	5	-	43.3

There are 10 plants/row and 6 rows per plot (treatment). However, there are 12 plants/row with 5 row per plot (treatment) in the trial at Saskatoon.

APPENDIX F. Yellow Asters Disease Evaluation in Herbs and Spices - 2000

Table 1. Effect of treatments on the control of phytoplasma diseases occurring on XXX at different locations of Saskatchewan in 2000.
Refer to Dr. Kan-Fa Chang report attached

APPENDIX G. Bioassay of organic insecticides on AY leafhoppers - 2000

Plant Treatment	Alive	Dead	Not found	% Dead	
Check 1	4	0	6	0	hole in cage
Check 2	9	1	0	10	
Check 3	10	0	0	0	
Check 4	8	2	0	20	
Check 5	10	0	0	0	
Check T	41	3	6	7	
Rotenone 1	5	3	2	38	
Rotenone 2	8	2	0	20	
Rotenone 3	9	1	0	10	
Rotenone 4	7	2	1	22	
Rotenone 5	9	1	0	10	
Rotenone T	38	9	3	19	
Pyrethrin 1	1	9	0	90	
Pyrethrin 2	1	9	0	90	
Pyrethrin 3	0	3	7	100	hole in cage
Pyrethrin 4	0	9	1	100	
Pyrethrin 5	0	10	0	100	
Pyrethrin T	2	40	8	95	
Neem 1	8	2	0	20	
Neem 2	6	4	0	40	
Neem 3	9	1	0	10	
Neem 4	9	1	0	10	
Neem 5	7	3	0	30	
Neem T	39	11	0	22	
DE 1	9	1	0	10	
DE 2	4	1	5	20	hole in cage
DE 3	9	1	0	10	
DE 4	9	1	0	10	
DE 5	10	0	0	0	
DE T	41	4	5	9	

Insect Treatment	24 hr Alive	24 hr Dead	48 hr Alive	48 hr Dead	72 hr Alive	72 hr Dead	96 hr Alive	96 hr Dead
Neem1	4	6	3	7	0	10	0	10
Neem2	4	6	3	7	3	7	3	7
Neem3	5	5	2	8	2	8	2	8
Neem4	3	7	3	7	3	7	2	8
Neem5	2	8	2	8	1	9	1	9
DE1	5	5	5	5	1	9	0	10
DE2	4	6	3	7	0	10	0	10
DE3	4	6	4	6	0	10	0	10
DE4	7	3	7	3	0	10	0	10
DE5	9	1	9	1	0	10	0	10
Py1	0	10	0	10	0	10	0	10
Py2	0	10	0	10	0	10	0	10
Py3	0	10	0	10	0	10	0	10
Py4	0	10	0	10	0	10	0	10
Py5	0	10	0	10	0	10	0	10
Ro1	10	0	10	0	4	6	1	9
Ro2	2	8	0	10	0	10	0	10
Ro3	10	0	9	10	0	10	0	10
Ro4	9*	0	6*	3	3	6	3	6
Ro5	4	6	0	10	0	10	0	10
Check1	10	0	10	0	9	1	6	4
Check2	10	0	10	0	1	9	1	9
Check3	10	0	10	0	3	7	3	7
Check4	10	0	10	0	1	9	0	10
Check5	10	0	10	0	0	10	0	10

* 1 escaped

Aster Yellows Control for Organic Production of Herbs and Spices

Final Report
November 23, 2000

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Abstract

Field trials to test the efficacy of foliar sprays of Pyrethrin, Rotenone, diatomaceous earth (D.E.), garlic oil and Neemix to control aster yellows (AY) were conducted in Saskatchewan in 1999 and in 2000. Disease incidence was recorded in field plots of caraway, coriander, echinacea, feverfew, and valerian set up at Aberdeen, Moose Jaw, Prince Albert and Saskatoon. Pyrethrin spray reduced AY incidence on feverfew more than the other treatments at Saskatoon in 1999, but none of the other spray treatments reduced disease incidence at any of the locations in either year. In 1999, *Echinacea angustifolia* had the lowest disease incidence among the crops showing disease at all locations, especially in Saskatoon. Almost no AY was found on seedlings of feverfew and coriander at Saskatoon. The disease incidence was lower at Aberdeen than at Moose Jaw. Despite low survival among valerian plants, AY occurred at every location. In both years, AY occurred at very low levels at all locations for annual caraway and coriander. Overall, the application of Pyrethrin, Rotenone, D.E., Neemix and garlic oil did not control the disease. More products should be selected and tested for their efficacy against this disease.

Background and Objectives

Echinacea (*Echinacea* spp.) is a widely grown herb and a potential cash crop for growers in Alberta. Extracts and powders from echinacea roots are used to strengthen the human immune system and have gained popularity in the herbal medicine market. Other medicinal and spice crops such as feverfew, valerian, caraway and coriander are also gaining popularity in the prairie provinces. Climatic conditions in the provinces are suitable for their growth, but disease problems often become the limiting factors for the production. Our research team identified aster yellows and sclerotinia stem rot on herbal crops as economically important diseases in Alberta and Saskatchewan (Chang *et al.*, 1997, 1998b, 1999a, 1999b, 2000a, 2000b, 2000c).

Aster yellows is caused by a phytoplasma (also known as mycoplasma, mycoplasma-like organisms or MLOs) (Hwang *et al.* 1997c). Diseased plants show leaf reddening, yellowing, stunting and witches' broom symptoms. Flowers in infected plants change into leaf-like structures and, consequently, fail to produce seeds (Hwang *et al.*, 1997b), which are the second-most valuable part of the plants. Forty percent of 2-yr-old *E. purpurea* (L.) Moench plants were infected with aster yellows at Lacombe in 1997 and over 80% plant infection was detected at Brooks in 1998 (Chang *et al.*, 1998a). Aster yellows of echinacea has also caused quite severe problems in Montana, USA (Dr. Nancy W. Callan, personal communication). Phytoplasmas are transmitted between plants primarily by leafhoppers (Insecta: Homoptera: Cicadellidae). An important method of disease control is to reduce leafhopper populations. The pathogen can infect other culinary and medicinal herbs such as caraway (*Carum carvi* L.), curled chervil (*Anthriscus*

cerefolium (L.) Hoffm.), evening primrose (*Oenothera biennis* L.), calendula (*Calendula officinalis* L.), monarda (*Monarda fistulosa* L.) and valerian (*Valeriana officinalis* L.) (Hwang *et al.*, 1997a, 1977b, 1997c). Recently, studies of phytoplasma DNA extracted from echinacea and monarda showed that they had a similar profile to DNA from the AY (aster yellows) phytoplasma (Khadhair *et al.*, 1997). Once plants are infected with a phytoplasma, there is no cure. Therefore, studies on the control of aster yellows disease in echinacea and other herbal crops are urgently needed. Many producers grow herbs under organic conditions as they command better returns. The use of organically acceptable insecticides would satisfy organic farming guidelines.

The objectives of this study are to

1) Monitor the distribution of aster yellows and migration patterns of leafhopper in Saskatchewan. (This part of research was conducted by Dr. Owen Olfert of AAFFC at Saskatoon), and

2) compile a list of organic management strategies for control of aster yellows and validate their efficacy under field conditions.

Materials and Methods

Pyrethrin, Rotenone, and Diatomaceous Earth (D.E.) were tested for their efficacy to control phytoplasma disease on caraway, coriander, echinacea, feverfew, and valerian at Aberdeen, Moose Jaw, Prince Albert and Saskatoon in the summers of 1999 and 2000. Garlic oil was sprayed onto tested crops at Saskatoon in 1999. In 2000, Neemix 4.5 was used in the trial. Field experiments including transplanting and spraying were conducted by Dr. Own Olfert and members of his crew. Seedlings were offered by Dr. Jazeem Wahab, Irrigation Diversification Centre, at Outlook. Garlic oil was applied only at Saskatoon. Seedlings of Echinacea, feverfew, and valerian were transplanted to field while caraway and coriander were directly sown into the ground in 30 x 6 m plots for each plant species. Organic insecticides and D.E. were applied to 10 m strips for each crop. Disease incidence in each plot, location and species was determined by visual examination of plants in the summer and/or fall. New crops of caraway and coriander were established in all locations in the summer of 2000. A new testing site was established at another location near Prince Albert in 2000. Seedlings of feverfew were transplanted into plots at Saskatoon in 2000. Data collected from each row in the plot were considered as a replicate and were subject to analysis of variance.

Results and Discussion

The results of the trial of pyrethrin, rotenone, diatomaceous earth and garlic oil applications to control of aster yellows on the tested crops at four locations of Saskatchewan in 1999 are presented in Table 1. The disease incidence varied with respect to crop type and among locations tested.

Infection rates of AY on echinacea and coriander crops were extremely low in most tested locations (Table 1). The same situation occurred on the annual crops of caraway indicating that the disease has a low impact on crop yield. On the feverfew and valerian crops, the disease incidence was lower at Aberdeen and Saskatoon than at Moose Jaw and Prince Albert. Most infected plants of feverfew showed leaf yellowing but less frequently showed phyllody symptoms. Valerian is the most susceptible crop to AY and the highest disease incidence occurred at Prince Albert followed by Moose Jaw and Saskatoon. The lowest infection rate of valerian, up to 20%, occurred at Aberdeen. Pyrethrin spray reduced AY incidence on feverfew more than the other treatments at Saskatoon in 1999. However, it did not reduce AY incidence on any of the other crops at this or at any of the other locations. Application of Rotenone and D.E. did not appear to control the disease on any of the tested crops. Garlic oil appeared to reduce disease incidence on valerian plants (5% incidence) at Saskatoon in 1999.

A second evaluation of AY incidence was conducted on these plots in July, 2000. Results are categorized by location in Table 2 and described by crop as follows:

Caraway and Coriander:

There was no AY apparent at any of the locations in July. The fields were re-examined for AY in early September and very low infection rates were found in all treatments at all locations. Although severely infected plants have been found in the past, low rates of infection may have resulted from the dense canopy that these crops develop early in the growing season under field conditions. This may limit the mobility of leafhoppers and consequently hamper transmission of the disease. In addition, both crops have a strong aromatic fragrance which may cause leafhoppers to prefer other food sources.

Echinacea angustifolia:

The crop still had the lowest disease incidence (<10%) among the tested crops at all locations, especially in Saskatoon where soil in the plots was quite dry. There was no significant difference in AY incidence among the treatments. The low disease incidence on *E angustifolia* may be due either to higher level of disease resistance, a low population of leaf hoppers, or a low preference for feeding on *E. angustifolia.*

Feverfew:

No AY was found on the 1-year-old plants at Saskatoon. The occurrence of AY was lower at Aberdeen than at Moose Jaw. Pyrethrin spray reduced the disease incidence more than the other treatments at Aberdeen in July, 2000.

Valerian:

More than 50% of the valerian plants were killed either by low temperatures or by root rot diseases at Aberdeen, Moose Jaw and Saskatoon (Table 3). This situation makes it difficult to accurately determine AY incidence among treatments. Typical symptoms of AY such as phyllody occurred at every location. Infected plants may have become weakened and phytoplasma bodies were translocated down to the roots along with nutrients. These weakened plants may be subject to further winter kill or other secondary infection caused by soil-borne pathogens. In most locations, the incidence of AY is higher than last year.

Insect and disease control by organic methods is usually more difficult than by using pesticides. For that reason, not all growers subscribe to organic farming methods. Therefore, traditional fungicides and pesticides applications still have their merits in controlling diseases and pests. The failure to control AY using spray of Pyrethrin, D.E. and Rotenone may be due to their short period of activity on plants. These chemicals are photosensitive and easily degraded.

In summary:

1. Aster yellows incidence varied with respect to crop type and among locations tested in Saskatchewan in both years. The incidence of AY was higher at all locations in 2000 than in 1999 for all tested crops. Echinacea crops showed the lowest disease incidence at all test locations.
2. Application of Pyrethrin, Rotenone, DE and garlic oil did not effectively control AY. More products should be selected and tested for their efficacy to control this disease.
3. Plants of valerian and echinacea infected with aster yellows may be prone to infection of soil-borne diseases which caused by *Fusarium* spp., *Sclerotinia sclerotiorum* or other pathogens.

Future study:

1. Selection/breeding for resistant cultivars. Seeds should be harvested from vigorously growing plants which show no symptoms of AY and are growing among heavily infected plant populations. Their progeny should be continuously tested under field conditions to confirm their resistance to the disease.

2. Screening of other essential oils/materials: More products such as commercially available horticultural oils (e.g. Sunoco Sunspray 6E, VolckR, JMS) and Consep soybean oil (Blocker™ Series) should be tested for their efficacy to control this disease.

Acknowledgments

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Table 1. Efficacy of pyrethrin, rotenone, diatomaceous earth and garlic oil application to control aster yellows in five crops at four locations in Saskatchewan in 1999.

Locations	Treatment	% Disease incidence				
		Caraway	Coriander	Echinacea	Feverfew	Valerian
Aberdeen	D.E.	0.2 bc	0.1	0	26.7 a	20.0 ab
	Pyrethrin	0.9 a	0.1	0	30.0 a	23.3 a
	Rotenone	0.7 ab	0.1	0	33.3 a	10.0 b
	Control 1	0.2 bc	0.1	0	33.3 a	10.0 b
	Control 2	0.1 c	0.1	0	35.0 a	13.3 ab
Moose Jaw	D.E.	4.7 a	0.4	0.6	33.3 bc	61.7 a
	Pyrethrin	4.7 a	0.2	0	51.7 a	53.3 ab
	Rotenone	3.7 a	0.4	0	46.7 ab	28.3 bc
	Control 1	2.8 a	0.1	0	43.3 abc	43.3 abc
	Control 2	3.3 a	0.2	0.6	30.0 c	38.3 c
Prince Albert	D.E.	3.3 a	1.4	3.3	58.3 a	86.7 a
	Pyrethrin	1.2 b	0.4	4.2	61.7 a	80.0 a
	Rotenone	2.0 ab	1	0	56.7 a	80.0 a
	Control 1	2.2 ab	1.2	1.7	60.0 a	91.7 a
	Control 2	2.3 ab	0.9	0.8	55.0 a	80.0 a
Saskatoon	D.E.	1.9 a	0	0	31.7 a	52.0 a
	Pyrethrin	2.1 a	0	0	23.3 a	30.0 a
	Rotenone	2.1 a	0	0	33.3 a	52.0 a
	Garlic oil	3.1 a	0	0	25.0 a	6.0 c
	Control	2.9 a	0.1	1	30.0 a	12.0 bc

Table 2. Efficacy of pyrethrin, rotenone, diatomaceous earth and garlic oil to control aster yellows on four crops at four locations in Saskatchewan in 2000.

Locations	Treatment	% Disease incidence			
		Caraway [X]	Coriander [X]	Echinacea	Feverfew
Aberdeen	D.E.	0.4	0.2	7.5	26.7
	Pyrethrin	0.4	0.2	4.2	30
	Rotenone	0.4	0.1	6.7	33.3
	Control	0.2	0.2	9.2	33.3
	Neemix	0	0.1	8.3	35
Moose Jaw	D.E.	0	0.2	1.3[W]	33.3
	Pyrethrin	0	0	1.9	51.7
	Rotenone	0	0.3	0.6	46.7
	Control	0	0.1	2.5	43.3
	Neemix	0	0.1	4.4	30
Prince Albert	D.E.	0.6	0	0 [Y]	3.3[Z]
	Pyrethrin	0.4	0.3	0	0
	Rotenone	0.2	0.3	0	3.3
	Control	0.5	0.3	0	6.7
	Neemix	1.2	0.3	0	3.3
Saskatoon	D.E.	0.2	0.7	0	0[Z]
	Pyrethrin	0	0.5	1	0
	Rotenone	0.8	0.6	0	2
	Control	0	0.4	0	0
	Neemix	0.8	0.8	0	8

[W] Many of the echinacea plants died. Incidence reflects the actual percentage infection among living plants.

[X] 1-yr-old crop of caraway & coriander.

[Y] Echinacea plants at Prince Albert are one year old.

[Z] Feverfew plants at Prince Albert and Saskatoon are one year old.

Table 3. Efficacy of pyrethrin, rotenone, diatomaceous earth and garlic oil to control aster yellows of valerian plants at two locations in Saskatchewan in 2000.

Location	Treatment	% Aster yellows[X]	% Mortality
Aberdeen	D.E.	3.3	96.7
	Pyrethrin	5.0	95.0
	Rotenone	5.0	95.0
	Control	3.3	96.7
	Neemix	0	100
Saskatoon	D.E.	18	78.0
	Pyrethrin	0	86.0
	Rotenone	2.0	74.0
	Control	2.0	84.0
	Neemix	2.0	82.0

[X] data indicates percentage of infection among surviving plants.

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For

The Saskatchewan Herb & Spice Association

THE ASTER YELLOWS PHYTOPLASMA

Hosts

Vectors

Geographical Distribution

Control

by Celine Burns, B.S.A.

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1 THE ASTER YELLOWS ORGANISM

1.1 History of the 'Virus-like' Organism

Aster yellows was so named because the China aster, *Callistephus chinensis*, was the first crop to be severely affected by the disease, and the most prominent disease symptom is a yellowing, or chlorosis, of the plant. As early as 1902, scientists were reporting widespread destruction of aster crops, and by 1926, growers in some parts of the eastern United States were abandoning the planting of asters because of infection rates as high as 90 to 95 percent (KUNKEL 1926). Up to this time, aster yellows was largely ignored by plant pathologists because virus diseases in general were understudied, and aster yellows did not affect any crops of economic importance. The disease was also unknown outside of North America.

KUNKEL (1926) described aster yellows as an "infectious chlorosis". KUNKEL grouped the disease with viruses because it had similar characteristics. Presumably, those characteristics included disease symptoms and the transmission by an insect vector. However, the organism was unable to be filtered like other plant viruses, and so this classification was tentative.

It is interesting to note that KUNKEL (1926) believed that aster yellows was endemic to North America and the primary vector, *Macrosteles fascifrons*, was imported perhaps 50 years before. This belief would explain the sudden surge of infections early in this century. As KUNKEL puts it, aster yellows was probably in existence in North America, infecting a native plant host that had a host-specific insect vector. However, with the importation of *M. fascifrons*, which has a wide host range, and the importation and subsequent cultivation of the China aster, *M. fascifrons* was able to acquire the aster yellows organism from a native plant and transfer the disease to aster and numerous other plants.

1.2 Phytoplasma vs. Mycoplasma-Like Organism (MLO)

The invention of the electron microscope brought about monumental change in the way plant pathologists viewed diseases such as aster yellows. The organism was discovered to be a wall-less microbe, much different from a virus. The microbe was described as a "mycoplasma-like organism" (MLO) because it initially seemed similar to known mollicutes that

caused disease in humans and animals (FLETCHER et al. 1998). However, further advances in technology allowed the evolutionary relationships of such organisms to be deciphered, and new classification systems to be developed. "Phytoplasmas" are now in a class of their own based on the plants ("phyto") which host them (SEARS & KIRKPATRICK 1994).

1.3 Symptoms of Aster Yellows

1.3.1 Chlorosis

KUNKEL (1926) described the main symptoms of aster yellows. The first indication of infection on a young plant is "clearing of the veins" which refers to a yellowing of part or all of the veins in new leaves. Subsequent new leaves show the same yellowed veins. As the disease progresses, the chlorosis spreads throughout the leaf. However, midribs or large veins may inhibit the spread of chlorosis, resulting in entire sections of the leaf remaining green. Also, entire parts of the plant may be slow to show yellowing, so that only half of the plant may appear to be infected. This yellowing was attributed to the disease's capability of destroying chlorophyll and indeed, GHOSH et al. (1988) reported degeneration of chloroplasts in *Nicotiana rustica* L. The degeneration was caused by the growth of the phytoplasmas within chloroplasts, which subsequently burst and released the organism into the sieve elements of the phloem. As the phloem carries nutrients throughout the plant, the organism could also be transported with the sap. KUNKEL (1926) emphasized that aster yellows could be easily distinguished from mosaic diseases because the chlorotic effect was never mottled in appearance. KUNKEL also noted the wide variance in effect that aster yellows has on individual plants. Among the same species of plant, one could be severely yellowed and stunted, while the next remained relatively green and full size.

1.3.2 Stunting

Young plants that are infected by aster yellows are almost always stunted to some degree (KUNKEL 1926). The extent to which stunting occurs depends on the age of the plant at infection. Internodes on the main stem become shortened, resulting in a stunted plant. However, secondary shoots often have lengthened internodes. Flower heads may sometimes be larger than normal; however, mostly they are dwarfed. Flowers may have branches growing out of them, some of which bear more small flowers.

1.3.3 Phyllody and Virescence

The flowers of plants infected with the aster yellows phytoplasma often show symptoms of both phyllody and virescence (HWANG et al. 1996). Phyllody refers to floral organs, such as petals, becoming leaflike. Virescence describes how parts of the plant that are not normally green, *ie.* flower petals, become green (McCOY et al. 1979). KUNKEL (1926) noted it was strange that while most of the plant suffered from chlorosis, flowers which normally contained no chlorophyll turned green when diseased.

1.3.4 Leaf Reddening

In addition to chlorosis, leaves may also turn red in colour (HWANG et al. 1996).

1.3.5 Morphological Effects

Leaves that are infected are often deformed and have lengthened petioles (KUNKEL 1926). The blade of the leaf is usually narrower than normal and the entire leaf smaller than normal. Leaf margins may also be notched and deep clefts may appear in the leaves.

1.3.6 Witches' Broom

Witches broom is another common symptom of aster yellows. It is characterized by the abnormal production of secondary shoots, producing a bunchy or broom-like effect. These shoots are usually thin and etiolated (pale with lengthened internodes) (KUNKEL 1926, HWANG et al. 1996).

1.3.7 Advanced Stages/Reduced Vigour

Eventually, the disease progresses to a point where parts of the plant begin to die. Main branches will typically show necrosis shortly below the apical bud (KUNKEL 1926). However, plants that escape further infection by fungi remain alive nearly as long as healthy plants. KUNKEL reported that both healthy and aster yellows-infected China asters were susceptible to a *Sclerotinia* disease, but that AY-infected asters were more readily attacked by the fungus than healthy asters. This secondary infection was the actual cause of plant death. SINHA (1983) also reported deterioration of older plants. Statice infected with yellows was susceptible to winter kill and secondary infection by soil-borne pathogens such as *Fusarium* (unpublished data from CHANG & MIRZA) and *Sclerotinia sclerotiorum* (CHANG et al. 1994, 1996b). HWANG et al.

(1997a), in Alberta, speculated that phytoplasma-infected *Echinacea* sp. had less food reserves because of the disease, and this was what caused reduced winter hardiness resulting in plant death. Diseased caraway was also less likely to overwinter in Alberta, and plants were unable to set seed (HWANG et al. 1997b). Again, monarda infected with a yellows phytoplama were observed to have reduced winter survival (HWANG et al. 1997c).

2 DISEASE DEVELOPMENT

2.1 Phytoplasma Reproduction in Host Plants

In experiments on the China aster (*Callistephus chinensis* Nees), SINHA (1983) measured the concentration of MLO-antigens at various stages of disease development. The antigens could only be detected two weeks after infection because the concentration before this time was too low to detect. However, between the 2nd and 8th week, antigens increased 16-fold and remained at this level for two weeks. This was followed by a decline to a low level by the 14th week. MLO examined under an electron microscope had begun to disintegrate by the 12th to 14th week.

2.2 Symptom Development

SINHA (1983) found that two weeks after infection, only 75 percent of asters showed any symptoms of the disease. MLO-antigens had doubled by the fourth week, and all plants displayed primary symptoms. Older infected plants deteriorated in condition. KUNKEL (1926) found similar incubation periods in asters.

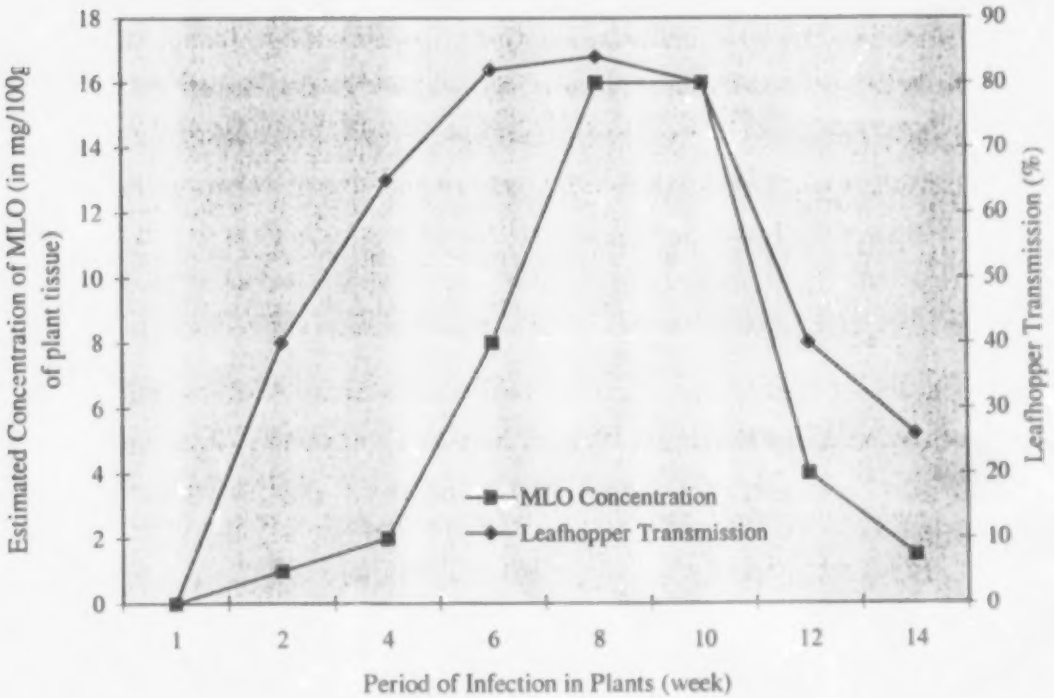
3 PHYTOPLASMA TRANSMISSION

3.1 Vector Transmission

In further reference to the work described in Section 2.1 by SINHA (1983), the number of leafhoppers (*M. fascifrons*) able to acquire and transmit the phytoplasma at various stages throughout disease development followed a pattern similar to that of the increase and decrease of MLO-antigens inside the plant, with minor variations. Leafhoppers were first able to acquire the phytoplasma two weeks after the plants had been infected. As the disease developed to the 8th to 10th week, the percentage of leafhoppers able to acquire and transmit the phytoplasma increased, and decreased thereafter. After 12 to 14 weeks, plants became poor sources of infection for

leafhoppers. It is interesting, however, that antigen levels in a 12-week infected plant were four times greater that that of a 2-week infected plant, but leafhopper transmission percentages at both points were the same. The disintegration of MLO at 12 to 14 weeks combined with plant deterioration from the disease may explain why leafhopper transmission decreased at about this time. It could be that deteriorating plants were less attractive to feeding leafhoppers. Figure 1 is a graph of data presented by SINHA (1983).

Figure 1 - Comparison of MLO-antigen Levels in Plant Tissues and Leafhopper Transmission Rates



Inconsistency in leafhopper transmission was first shown by KUNKEL (1926). Leafhoppers only infected about three-quarters of healthy aster plants that they were moved to daily.

3.2 Mechanical Transmission

KUNKEL (1926) was unsuccessful in all attempts to transmit the disease mechanically, except by budding. This grafting of diseased plant material onto a healthy plant did result in infection

of the healthy plant with aster yellows. TSAI (1979) reported that MLOs are not sap-transmissible, and can only be spread by insects.

3.3 Transmission Through Seed

Although most virus diseases, for example legume mosaics, were known to be transferable through seed from an infected plant, KUNKEL (1926) tentatively concluded that aster yellows could not be transferred through aster seed. Mollicutes cannot be transmitted through seed, but are occasionally transmitted in nature through root grafts (KIRKPATRICK 1989). DOSHEIDT (1997) also contends that phytoplasmas cannot be conveyed in seed.

3.4 Transmission Through Vector Eggs

KUNKEL (1926) indicated that eggs of the leafhopper vector did not carry the 'virus'. DOSHEIDT (1997) agreed that phytoplasma cannot be transferred through insect eggs. It was long thought that leafhoppers could not pass phytoplasma to offspring; however, recently ALMA et al. (1997) in Italy detected phytoplasmas in progeny of the leafhopper *Scaphoideus titanus*, a European vector of Grapevine Yellows (GY). GY belongs to the aster yellows group of phytoplasmas. ALMA et al. also tested offspring of *Macrosteles quadripunctulatus* (Kirschbaum) and *Eusecelis variegatus* (Kirschbaum) but tests were negative for GY. The need for further confirmation of phytoplasma transfer from parent to offspring was stressed.

On the prairies, leafhoppers can only survive the winter as eggs; adults and nymphs do not endure the cold temperatures (HWANG et al. 1996). Phytoplasmas need living tissue of plant hosts or leafhoppers to survive. In spite of the recent developments noted in the previous paragraph, eggs of *M. fascifrons* have never been shown to carry the aster yellows phytoplasma. Therefore, newly hatched local populations of leafhoppers are not infective on the prairies until they feed upon infected plant material. This plant material could be newly infected by viruliferous migrant leafhoppers. However, because aster yellows does not outright kill its host plants, it is likely that biennials and perennials infected the previous year, whether weeds or crops, provide primary inoculum for local leafhopper populations.

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3.5 Phytoplasma Overwintering in Plant Hosts

In 1926, aster yellows was known to overwinter in biennial and perennial plant hosts (KUNKEL 1926). In Minnesota, aster yellows overwinters in many weed hosts, such as horseweed, volunteer parsnip and dandelion (ERRAMPALLI et al. 1991). In 1961, WESTDAL et al. reported infectious leafhoppers in a locally developed Manitoba population; this led to the conclusion that leafhoppers were obtaining the phytoplasma from a local source.

4 PHYTOPLASMA CLASSIFICATION

4.1 Current Classification

LEE et al. (1998) has summarized data from numerous sources into a table which lists 14 major phytoplasma groups and 38 subgroups, based on RFLP analyses of 16Sr RNA (16Sr) and ribosomal protein (rp) gene sequences. Geographical distribution is also included in the table. Sections from the major group, aster yellows (16SrI), which have a worldwide or North American distribution have been reproduced in Table 1 below.

Table 1 - Classification of Phytoplasmas

Diseases(s)	Primary phytoplasma(s) associated	Vector	Geographic Distribution
North American aster yellows (eastern)	16SrI-A, 16SrI-A (rp-A)	reported	North America
Aster yellows (western)	16SrI-B, 16SrI-B (rp-B)	reported	Worldwide
Lettuce yellows	16SrI-A, -B	reported	North America, Italy
Maize bushy stunt	16SrI-B, 16SrI-B (rp-L)	reported	America
Clover phyllody, strawberry green petal	16SrI-C	reported	North America, Europe
Blueberry stunt	16SrI-E	reported	North America

LEE et al. (1998) also indicates that vectors are able to transmit multiple phytoplasmas and plants can have multiple phytoplasma infections.

4.2 Bolt vs. Severe Strains

MURRAL et al. (1996) describes two Ohio strains of aster yellows. The *bolt* strain has distinct symptoms which include elongated internodes and severe stem and petiole chlorosis. The *severe* strain results in stunted plants. Vein clearing, general chlorosis, virescence and phyllody are

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Lettuce yellows	16SrI-A, -B	reported	North America, Italy
Maize bushy stunt	16SrI-B, 16SrI-B (rp-L)	reported	America
Clover phyllody, strawberry green petal	16SrI-C	reported	North America, Europe
Blueberry stunt	16SrI-E	reported	North America

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common to both strains. The strains are distinct when infecting China aster and 'Oakleaf' green leaf lettuce.

4.3 Previous Names of Western and Eastern Strains

CAYA, also known as CAY-MLO, describes a celery-infecting strain of aster yellows (CHIYKOWSKI 1991a). A western strain isolated in Alberta was called AY27 (KHADHAIR et al. 1998). The western strain was once thought to be unique in its ability to infect celery (CHIYKOWSKI 1977). The eastern strain has also been known as the New York strain (MILLER & DE LYZER 1960), EAY (WANG et al. 1998), EAYA (CHIYKOWSKI 1978) and NAY-MLO (CHIYKOWSKI 1991a). Celery was thought to be non-susceptible to this eastern strain (MILLER & DE LYZER 1960). However, in 1978, CHIYKOWSKI compared EAYA and CAYA for their ability to infect celery. In fact, EAYA could infect celery, but symptom expression took nearly three times as long (average of 115 days *vs.* 40 days for CAYA). Also, only about 75 percent of celery plants became infected with EAYA, while CAYA infected 100 percent. *M. fascifrons* also had a more difficult time acquiring EAYA from celery than CAYA. Severin, in 1929, first showed that *M. fascifrons* could transmit the western strain (NEILSON 1968). Kunkel was the first to show transmission of the eastern strain by *M. fascifrons* in 1924 (NEILSON 1968).

5 REPORTED HOSTS OF ASTER YELLOWS

As early as 1926, KUNKEL reported that aster yellows could be experimentally induced to infect more than 50 different species in 23 families of plants. However, he indicated that not all plant species exhibit the total array of symptoms normally associated with aster yellows. He proved that plants exhibiting only limited symptoms such as witches' broom or vein clearing were truly infected by using these plants as sources for the leafhopper carrier to transmit the phytoplasma back to aster, whereupon all the typical symptoms would appear. The following is a list of plant families containing species which have been reported to be infected by the aster yellows phytoplasma:

- Acanthaceae
- Aizoaceae
- Amaranthaceae
- Amaranthaceae
- Cistaceae
- Cruciferae
- Cucurbitaceae
- Datiscaceae
- Papaveraceae
- Plantaginaceae
- Plumbaginaceae
- Poaceae

- Apiaceae
- Apiaceae
- Apocynaceae
- Asclepiadaceae
- Asteraceae/ Compositae
- Begoniaceae
- Boraginaceae
- Brassicaceae
- Campanulaceae
- Cannabinaceae
- Caryophyllaceae
- Chenopodiaceae
- Dipsacaceae
- Fabaceae
- Geraniaceae
- Gesneriaceae
- Hydrophyllaceae
- Labiatae
- Limmanthaceae
- Loasaceae
- Malvaceae
- Martyniaceae
- Nyctaginaceae
- Onagraceae
- Polemoniaceae
- Polygonaceae
- Portulacaceae
- Primulaceae
- Ranunculaceae
- Resedaceae
- Rosaceae
- Scrophulariaceae
- Solanaceae
- Umbelliferae
- Urticaceae
- Valerianaceae

(CHANG et al. 1996a; HWANG et al. 1997b; HWANG et al. 1997c; WANG et al. 1998; HWANG et al. 1997d; HWANG et al. 1998; WHITCOMB & TULLY 1979; KUNKEL 1926)

The following table lists plant species which have been reported to be infected by the aster yellows phytoplasma:

Table 2 - List of Aster Yellows Plant Hosts, Grouped by Latin Name

Latin Name	Common Name	Location	Reference
	pineapple weed	USA	GABELMAN et al. 1994
	dodder	USA	GABELMAN et al. 1994
	sunflower	Ontario	McCLANAHAN 1963; MILLER & DE LYZER 1960
	flax	Manitoba Minnesota North Dakota South Dakota Ontario	MARTIN et al. 1961; McCLANAHAN 1963; MILLER & DE LYZER 1960
	endive	New York	VERNON et al. 1942
Allium ascalonicum	shallot	Louisiana	WHITCOMB & TULLY 1979
Allium cepa	onion	California	WHITCOMB & TULLY 1979
Alyssum compactum procumbens	sweet alyssum	(laboratory)	KUNKEL 1926
Amaranthus auroro		(laboratory)	KUNKEL 1926
Amaranthus caudatus		(laboratory)	KUNKEL 1926
Amaranthus retroflexus	rough pigweed	California	WHITCOMB & TULLY 1979
Ambrosia artemisiifolia	hogweed	(laboratory)	KUNKEL 1926
Ambrosia trifida	horseweed	(laboratory)	KUNKEL 1926
Ammobium alatum	ammobium	(laboratory)	KUNKEL 1926
Anagallis arvensis	scarlet pimpernel	California	WHITCOMB & TULLY 1979
Anemone coronaria	poppy anemone	California	WHITCOMB & TULLY 1979
Anethum graveolens	dill	(laboratory) Texas	KUNKEL 1926 WHITCOMB & TULLY 1979
Anthemis cotula	mayweed	California	WHITCOMB & TULLY 1979
Aphanostephus humilis	lazy daisy	Texas	WHITCOMB & TULLY 1979

- Apiaceae
- Apiaceae
- Apocynaceae
- Asclepiadaceae
- Asteraceae/ Compositae
- Begoniaceae
- Boraginaceae
- Brassicaceae
- Campanulaceae
- Cannabinaceae
- Caryophyllaceae
- Chenopodiaceae
- Dipsacaceae
- Fabaceae
- Geraniaceae
- Gesneriaceae
- Hydrophyllaceae
- Labiatae
- Limmanthaceae
- Loasaceae
- Malvaceae
- Martyniaceae
- Nyctaginaceae
- Onagraceae
- Polemoniaceae
- Polygonaceae
- Portulacaceae
- Primulaceae
- Ranunculaceae
- Resedaceae
- Rosaceae
- Scrophulariaceae
- Solanaceae
- Umbelliferae
- Urticaceae
- Valerianaceae

(CHANG et al. 1996a; HWANG et al. 1997b; HWANG et al. 1997c; WANG et al. 1998; HWANG et al. 1997d; HWANG et al. 1998; WHITCOMB & TULLY 1979; KUNKEL 1926)

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Amaranthus caudatus		(laboratory)	KUNKEL 1926
Amaranthus retroflexus	rough pigweed	California	WHITCOMB & TULLY 1979
Ambrosia artemisiifolia	hogweed	(laboratory)	KUNKEL 1926
Ambrosia trifida	horseweed	(laboratory)	KUNKEL 1926
Ammobium alatum	ammobium	(laboratory)	KUNKEL 1926
Anagallis arvensis	scarlet pimpernel	California	WHITCOMB & TULLY 1979
Anemone coronaria	poppy anemone	California	WHITCOMB & TULLY 1979
Anethum graveolens	dill	(laboratory) Texas	KUNKEL 1926 WHITCOMB & TULLY 1979
Anthemis cotula	mayweed	California	WHITCOMB & TULLY 1979
Aphanostephus humilis	lazy daisy	Texas	WHITCOMB & TULLY 1979

Latin Name	Common Name	Location	Reference
Apium graveolens	celery	Ontario Minnesota California Ohio	McCLANAHAN 1963; MILLER & DE LYZER 1960; SETIAWAN & RAGSDALE 1987; ZALOM 1981; WHITCOMB & TULLY 1979; CHIYKOWSKI 1978; MURRAL et al. 1996
Apium graveolens rapaceum	celeriac	California	WHITCOMB & TULLY 1979
Asclepias nivea		(laboratory)	KUNKEL 1926
Aster novae-angliae	New England aster	Ontario	WHITCOMB & TULLY 1979
Avena sativa	oats	Manitoba	WHITCOMB & TULLY 1979
Begonia semperflorens	Begonia	(laboratory)	KUNKEL 1926
Bidens frondosa	beggar-ticks	California	WHITCOMB & TULLY 1979
Bidens pilosa	hairy bur marigold	California	WHITCOMB & TULLY 1979
Blumenbachia hieronymii		(laboratory)	WHITCOMB & TULLY 1979
Brachycome iberidifolia	swan river daisy	California	WHITCOMB & TULLY 1979
Brassica campestris	rapeseed	Alberta Saskatchewan California	CONN et al. 1993; PETRIE 1973; WHITCOMB & TULLY 1979
Brassica napus	rapeseed	Alberta Saskatchewan	CONN et al. 1993; PETRIE 1973
Brassica oleracea var. *botrytis*	cauliflower	California	WHITCOMB & TULLY 1979
Brassica oleracea var. *capitata*	cabbage	California	WHITCOMB & TULLY 1979
Brassica oleracea var. *italica*	broccoli	California	WHITCOMB & TULLY 1979
Cajophora lateritia		(laboratory)	WHITCOMB & TULLY 1979
Calandrinia grandiflora	rock purslane	(laboratory)	KUNKEL 1926
Calceolaria		(laboratory)	KUNKEL 1926
Calendula officinalis	pot marigold	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Calliopsis		(laboratory)	KUNKEL 1926
Callistephus chinensis	China aster	Ottawa Manitoba N. Amer.	CHIYKOWSKI 1977; WESTDAL et al. 1961; KUNKEL 1926
Callistephus sp.	aster	Ottawa	CHIYKOWSKI 1978
Capsella bursa-pastoris	shepherd's purse	California	WHITCOMB & TULLY 1979
Catharanthus roseus	periwinkle	(laboratory)	WHITCOMB & TULLY 1979
Centaurea americana	basket flower	California	WHITCOMB & TULLY 1979
Centaurea cyanus	cornflower	California	WHITCOMB & TULLY 1979
Centaurea imperialis	Centaurea	(laboratory)	KUNKEL 1926
Centaurea margaritae	Centaurea	(laboratory)	KUNKEL 1926
Centranthus calcitrapa	centranth	(laboratory)	WHITCOMB & TULLY 1979
Cheiranthus cheiri	wallflower	California	WHITCOMB & TULLY 1979
Chrysanthemum carinatum	tricolor Chrysanthemum	California	WHITCOMB & TULLY 1979
Chrysanthemum cinerariifolium	pyrethrum	New York	WHITCOMB & TULLY 1979
Chrysanthemum coronarium	crown daisy	(laboratory) USA	KUNKEL 1926; WHITCOMB & TULLY 1979
Chrysanthemum frutescens	marguerite	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Chrysanthemum leucanthemum	ox-eye daisy	(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Chrysanthemum leucanthemum maximum	moon penny daisy	(laboratory)	KUNKEL 1926
Chrysanthemum maximum	shasta daisy	(laboratory)	KUNKEL 1926
Chrysanthemum segetum	corn chrysanthemum	California	WHITCOMB & TULLY 1979
Chrysanthemum sp.	feverfew	(laboratory)	KUNKEL 1926
Chrysanthemum sp.	swan river daisy	(laboratory)	KUNKEL 1926
Cichorium endivia	endive	New York	WHITCOMB & TULLY 1979
Cichorium intybus	common chicory	California	WHITCOMB & TULLY 1979
Cilia capitata	globe gilia	California	WHITCOMB & TULLY 1979
Clarkia concinna	red ribbons	California	WHITCOMB & TULLY 1979
Clarkia unguiculata	Clarkia	New York	WHITCOMB & TULLY 1979
Consolida ajacis	rocket larkspur	California	WHITCOMB & TULLY 1979
Conyza canadensis	horseweed	California	WHITCOMB & TULLY 1979
Coreopsis drummondi	tickseed	California	WHITCOMB & TULLY 1979
Coreopsis grandiflora	tickseed	California	WHITCOMB & TULLY 1979
Coreopsis lanceolata	tickseed	New York	WHITCOMB & TULLY 1979
Coriandrum sativum	coriander	California	WHITCOMB & TULLY 1979
Cosmidium		(laboratory)	KUNKEL 1926
Cosmos bipinnatus	Cosmos	New York	WHITCOMB & TULLY 1979
Cucurbita mixta		(laboratory)	WHITCOMB & TULLY 1979
Cucurbita moschata	musky gourd	California	WHITCOMB & TULLY 1979
Cucurbita pepo	pumpkin	California	WHITCOMB & TULLY 1979
Datisca cannabina	akalbir	(laboratory)	WHITCOMB & TULLY 1979
Daucus carota	carrot	Ontario P.E.I. Manitoba Minnesota California	McCLANAHAN 1960; MILLER & LYZER 1969; CHIYKOWSKI 1973; HENNE 1979; WESTON et al. 1981; SETIAWAN & RAGSDALE 1981; ZALOM 1981; WHITCOMB & TULLY 1979
Daucus carota var. *sativa*	carrot	Ohio Quebec	MURRAL et al. 1996; ARCELIN & KUSHALAPPA 1991
Delphinium x cultorum	hybrid larkspur	California	WHITCOMB & TULLY 1979
Dianthus		(laboratory)	KUNKEL 1926
Dianthus barbatus	sweet william	California	WHITCOMB & TULLY 1979
Dianthus caryophyllus	carnation	Colorado	WHITCOMB & TULLY 1979
Didiscus caeruleus		(laboratory)	KUNKEL 1926
Didymocarpus horsfieldii		(laboratory)	WHITCOMB & TULLY 1979
Dimorpholheca aurantiacum	African daisy	(laboratory)	KUNKEL 1926
Dipsacus fullonum	Fuller's teasel	California	WHITCOMB & TULLY 1979
Dyssodia wrighii	Fetid marigold	Texas	WHITCOMB & TULLY 1979
Echinacea purpurea	purple coneflower	Wisconsin Alberta	STANOSZ & HEIMANN 1997; KHADHAIR et al. 1997a
Echinacea sp.	purple coneflower	Wisconsin	per Comm. D. MAXWELL 1999
Epilobium californicum	California willow herb	California	WHITCOMB & TULLY 1979
Epilobium paniculatum	panicled willow herb	California	WHITCOMB & TULLY 1979
Erigeron annuus	daisy fleabane	(laboratory)	KUNKEL 1926
Erigeron canadensis	horseweed	(laboratory) Washington	KUNKEL 1926; WHITCOMB & TULLY 1979
Erigeron linifolius	flax-leaved fleabane	California	WHITCOMB & TULLY 1979
Erigeron philadelphicus	Philadelphia fleabane	New York	WHITCOMB & TULLY 1979
Erodium moschatum	whitestem filaree	California	WHITCOMB & TULLY 1979
Eschscholzia californica	California poppy	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Fagopyrum esculentum	buckwheat	(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Apium graveolens	celery	Ontario	McCLANAHAN 1963; MILLER & DE
		Minnesota	LYZER 1960; SETHAWAN &
		California	RAGSDALE 1987; ZALOM 1981;
		Ohio	WHITCOMB & TULLY 1979;
			CHIYKOWSKI 1978; MURRAL et al
			1996
Apium graveolens rapaceum	celeriac	California	WHITCOMB & TULLY 1979
Archgetia scorp		(laboratory)	KUNKEL 1926
Aster novae-angliae	New England aster	Ontario	WHITCOMB & TULLY 1979
Avena sativa	oats	Manitoba	WHITCOMB & TULLY 1979
Begonia semperflorens	Begonia	(laboratory)	KUNKEL 1926
Bidens frondosa	beggar-ticks	California	WHITCOMB & TULLY 1979
Bidens pilosa	hairy bur marigold	California	WHITCOMB & TULLY 1979
Blumeabalsamifera cernua		(laboratory)	WHITCOMB & TULLY 1979
Brachycome iberidifolia	swan river daisy	California	WHITCOMB & TULLY 1979
Brassica campestris	rapeseed	Alberta	CONN et al. 1993; PETRIE 1973;
		Saskatchewan	WHITCOMB & TULLY 1979
		California	
Brassica napus	rapeseed	Alberta	CONN et al. 1993; PETRIE 1973
		Saskatchewan	
Brassica oleracea var *botrytis*	cauliflower	California	WHITCOMB & TULLY 1979
Brassica oleracea var *capitata*	cabbage	California	WHITCOMB & TULLY 1979
Brassica oleracea var *italica*	broccoli	California	WHITCOMB & TULLY 1979
Capsella lateritia		(laboratory)	WHITCOMB & TULLY 1979
Catalpa bignonioides	rock purslane	(laboratory)	KUNKEL 1926
Calceolaria		(laboratory)	KUNKEL 1926
Calendula officinalis	pot marigold	(laboratory)	KUNKEL 1926; WHITCOMB &
		California	TULLY 1979
Calliopsis		(laboratory)	KUNKEL 1926
Callistephus chinensis	Chinaaster	Ottawa	CHIYKOWSKI 1977; WESTDAL et
		Manitoba	al. 1961; KUNKEL 1926
		N. Amer.	
Callistephus sp.	aster	Ottawa	CHIYKOWSKI 1978
Capella bursa-pastoris	shepherd's purse	California	WHITCOMB & TULLY 1979
Catharanthus roseus	periwinkle	(laboratory)	WHITCOMB & TULLY 1979
Centaurea americana	basket flower	California	WHITCOMB & TULLY 1979
Centaurea cyanus	cornflower	California	WHITCOMB & TULLY 1979
Centaurea imperialis	Centaurea	(laboratory)	KUNKEL 1926
Centaurea margaritae	Centaurea	(laboratory)	KUNKEL 1926
Centaurea moschata	sweet sultan	(laboratory)	WHITCOMB & TULLY 1979
Cheiranthus cheiri	wallflower	California	WHITCOMB & TULLY 1979
Chrysanthemum coronarium	double Chrysanthemum	California	WHITCOMB & TULLY 1979
Chrysanthemum cinerariifolium	pyrethrum	New York	WHITCOMB & TULLY 1979
Chrysanthemum coronarium	crown daisy	(laboratory)	KUNKEL 1926; WHITCOMB &
		USA	TULLY 1979
Chrysanthemum frutescens	marguerite	(laboratory)	KUNKEL 1926; WHITCOMB &
		California	TULLY 1979
Chrysanthemum leucanthemum	ox-eye daisy	(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Chrysanthemum leucanthemum maximum	moon penny daisy	(laboratory)	KUNKEL 1926
Chrysanthemum maximum	shasta daisy	(laboratory)	KUNKEL 1926
Chrysanthemum segetum	corn chrysanthemum	California	WHITCOMB & TULLY 1979
Chrysanthemum sp.	feverfew	(laboratory)	KUNKEL 1926
Chrysanthemum sp.	swan river daisy	(laboratory)	KUNKEL 1926
Cichorium endivia	endive	New York	WHITCOMB & TULLY 1979
Cichorium intybus	common chicory	California	WHITCOMB & TULLY 1979
Cilia capitata	globe gilia	California	WHITCOMB & TULLY 1979
Clarikia concinna	red ribbons	California	WHITCOMB & TULLY 1979
Clarkia unguiculata	Clarkia	New York	WHITCOMB & TULLY 1979
Consolida ajacis	rocket larkspur	California	WHITCOMB & TULLY 1979
Conyza canadensis	horseweed	California	WHITCOMB & TULLY 1979
Coreopsis drummondi	tickseed	California	WHITCOMB & TULLY 1979
Coreopsis grandiflora	tickseed	California	WHITCOMB & TULLY 1979
Coreopsis lanceolata	tickseed	New York	WHITCOMB & TULLY 1979
Coriandrum sativum	coriander	California	WHITCOMB & TULLY 1979
Cosmidium		(laboratory)	KUNKEL 1926
Cosmos bipinnatus	Cosmos	New York	WHITCOMB & TULLY 1979
Cucurbita mixta		(laboratory)	WHITCOMB & TULLY 1979
Cucurbita moschata	musky gourd	California	WHITCOMB & TULLY 1979
Cucurbita pepo	pumpkin	California	WHITCOMB & TULLY 1979
Datisca cannabina	akalbu	(laboratory)	WHITCOMB & TULLY 1979
Daucus carota	carrot	Ontario P.E.I. Manitoba Minnesota California	McCLANAHAN 1963; MILLER & DE LYZER 1960; CHIYKOWSKI 1978; HENNE 1970; WESTDAL et al. 1961; SETIAWAN & RAGSDALE 1987; ZALOM 1981; WHITCOMB & TULLY 1979
Daucus carota var. *sativa*	carrot	Ohio Quebec	MURRAY et al. 1986; ARCILLA & KUSHALAPPA 1991
Delphinium x ***cultorum***	hybrid larkspur	California	WHITCOMB & TULLY 1979
Dianthus		(laboratory)	KUNKEL 1926
Dianthus barbatus	sweet william	California	WHITCOMB & TULLY 1979
Dianthus caryophyllus	carnation	Colorado	WHITCOMB & TULLY 1979
Didiscus caeruleus		(laboratory)	KUNKEL 1926
Didymocarpus hossfieldii		(laboratory)	WHITCOMB & TULLY 1979
Dimorphotheca aurantiacum	African daisy	(laboratory)	KUNKEL 1926
Dipsacus fullonum	Fuller's teasel	California	WHITCOMB & TULLY 1979
Dyssodia wrightii	Fetid marigold	Texas	WHITCOMB & TULLY 1979
Echinacea purpurea	purple coneflower	Wisconsin Alberta	STANOSZ & HEIMANN 1997; KHATIAR et al. 1997a
Echinacea sp.	purple coneflower	Wisconsin	pers. comm. D. MAXWELL 1999
Epilobium californicum	California willow herb	California	WHITCOMB & TULLY 1979
Epilobium paniculatum	panicled willow herb	California	WHITCOMB & TULLY 1979
Erigeron annuus	daisy fleabane	(laboratory)	KUNKEL 1926
Erigeron canadensis	horseweed	(laboratory) Washington	KUNKEL 1926; WHITCOMB & TULLY 1979
Erigeron linifolius	flax leaved fleabane	California	WHITCOMB & TULLY 1979
Erigeron philadelphicus	Philadelphia fleabane	New York	WHITCOMB & TULLY 1979
Erodium moschatum	whitestem filaree	California	WHITCOMB & TULLY 1979
Eschscholzia californica	California poppy	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Eupgyrum esculentum	buckwheat	(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Fragaria x ananassa	garden strawberry	California Canada	WHITCOMB & TULLY 1979
Gaillardia aristata	Gaillardia	(laboratory)	KUNKEL 1926
Gaillardia pulchella	roseing gaillardia	California	WHITCOMB & TULLY 1979
Galinsoga parviflora	smallflower galinsoga	New York	WHITCOMB & TULLY 1979
Gaura lindheimeri	white gaura	California	WHITCOMB & TULLY 1979
Geum chiloense	Geum	California	WHITCOMB & TULLY 1979
Gladiolus hybrid	gladiole	Maryland (laboratory)	WHITCOMB & TULLY 1979 KUNKEL 1926
Gnaphalium decurrens	California everlasting	California	WHITCOMB & TULLY 1979
Gnaphalium purpureum	pink everlasting	California	WHITCOMB & TULLY 1979
Gypsophila paniculata	baby's breath	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Helenium autumnale	common sneezeweed	New York	WHITCOMB & TULLY 1979
Helenium latifolium	sneezeweed	Texas	WHITCOMB & TULLY 1979
Helenium nudiflorum	purplehead sneezeweed	New York	WHITCOMB & TULLY 1979
Helenium puberulum	rosilla	California	WHITCOMB & TULLY 1979
Helianthemum chamaecistus	rockrose	(laboratory)	WHITCOMB & TULLY 1979
Helianthus annuus	common sunflower	California	WHITCOMB & TULLY 1979
Helichrysum arenarium	strawflower	(laboratory)	KUNKEL 1926
Helichrysum bracteatum	strawflower	California	WHITCOMB & TULLY 1979
Hemizonia corymbosa	coast tarweed	California	WHITCOMB & TULLY 1979
Hordeum vulgare	barley	(laboratory)	CHIYKOWSKI 1991a
Hosackia dubia		California	WHITCOMB & TULLY 1979
Lactuca sativa	lettuce	(laboratory) Ontario Minnesota Manitoba California Ohio	KUNKEL 1926; McCLANAHAN 1963; MILLER & DE LYZER 1960; SETIAWAN & RAGSDALE 1987; ZALOM 1981; LEE & ROBINSON 1958; NICHIPORICK 1965; WHITCOMB & TULLY 1979; MURRAL et al. 1996
Lactuca scariola var. integrata	prickly lettuce	California	WHITCOMB & TULLY 1979
Lactuca serriola	prickly lettuce	New York	WHITCOMB & TULLY 1979
Lactuca spp. (alba x canadensis, floridana, graminifolia, ludoviciana, pulchella, saligna, sanguinea, virosa, special segregates, virosa)	lettuce	USA	WHITCOMB & TULLY 1979
Lamium amplexicaule	dead henbit nettle	California	WHITCOMB & TULLY 1979
Lavender	cultivated lavender	(laboratory)	KUNKEL 1926
Leontodon autumnalis	fall dandelion	New York	WHITCOMB & TULLY 1979
Limonium sinuatum	sea lavender	California	WHITCOMB & TULLY 1979
Limonium spp.	perennial statice	California	BAKER et al. 1983
Linaria bipartita	clown lip toadflax	California	WHITCOMB & TULLY 1979
Linaria canadensis	oldfield toadflax	California	WHITCOMB & TULLY 1979
Lobelia erinus var. compacta	edging lobelia	(laboratory)	WHITCOMB & TULLY 1979
Lycopersicon esculentum	tomato	California	WHITCOMB & TULLY 1979
Malva parviflora	little mallow	California	WHITCOMB & TULLY 1979
Malva rotundifolia	common mallow	California	WHITCOMB & TULLY 1979
Marigold		(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Matricaria matricarioides	pineapple weed	Ontario	WHITCOMB & TULLY 1979
Matricaria suaveolens	pineapple weed	California	WHITCOMB & TULLY 1979
Medicago hispida	bur-clover	California	WHITCOMB & TULLY 1979
Mimulus cardinalis	scarlet monkey-flower	California	WHITCOMB & TULLY 1979
Mimulus guttatus	common monkey-flower	California	WHITCOMB & TULLY 1979
Mimulus luteus	monkey flower	(laboratory)	KUNKEL 1926
Monarda fistulosa	monarda	Alberta	HWANG et al. 1997c; WANG et al. 1998; KHADHAIR et al. 1997
Myosotis scorpioides	forget-me-not	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Nemesia		(laboratory)	KUNKEL 1926
Nemophila		(laboratory)	KUNKEL 1926
Nicotiana rustica	wild tobacco	(laboratory)	KUNKEL 1937; WHITCOMB & TULLY 1979
Nigella damascena	love-in-a-mist	California	WHITCOMB & TULLY 1979
Parthenium hysterophorus	Santa Maria	Texas	WHITCOMB & TULLY 1979
Pastinaca sativa	parsnip	New York	WHITCOMB & TULLY 1979
Petroselinum crispum	parsley	California	WHITCOMB & TULLY 1979
Petroselinum hortense	parsley	Alberta	KHADHAIR et al. 1998
Petunia x hybrida	garden petunia	California	WHITCOMB & TULLY 1979
Phlox drummondii	annual phlox	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Phlox paniculata		(laboratory)	KUNKEL 1926
Picris echioides	bristly oxtongue	California	WHITCOMB & TULLY 1979
pimpinella anisum	anise	(laboratory)	KUNKEL 1926
Plantago major	great plantain	(laboratory) New York	KUNKEL 1926; WHITCOMB & TULLY 1979
Polygonum convolvulus	black bindweed	California	WHITCOMB & TULLY 1979
Portulaca		(laboratory)	KUNKEL 1926
Portulaca oleracea	purslane	(laboratory)	WHITCOMB & TULLY 1979
Primula elatior		(laboratory)	KUNKEL 1926
Primula polyantha	polyanthus primrose	California	WHITCOMB & TULLY 1979
Pyrrhopappus multicaulis	false dandelion	Texas	WHITCOMB & TULLY 1979
Ranunculus asiaticus	Persian buttercup	California	WHITCOMB & TULLY 1979
Reseda odorata	mignonette	(laboratory)	KUNKEL 1926
Rorippa curvisiliqua	western yellow cress	California	WHITCOMB & TULLY 1979
Rudbeckia hirta	hairy coneflower	New York	WHITCOMB & TULLY 1979
Rumex acetosa	sheep sorrel	California	WHITCOMB & TULLY 1979
Salpiglossis		(laboratory)	KUNKEL 1926
Salpiglossis sinuata	painted-tongue	California	WHITCOMB & TULLY 1979
Salvia azurea	azure sage	California	WHITCOMB & TULLY 1979
Satureia hortensis	summer savory	(laboratory)	KUNKEL 1926
Scabiosa atropurpurea	sweet scabious	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Schizanthus		(laboratory)	KUNKEL 1926
Scorzonera hispanica	black salsify	California	WHITCOMB & TULLY 1979
Senecio vulgaris	common groundsel	California	WHITCOMB & TULLY 1979
Silene pendula		(laboratory)	KUNKEL 1926
Solanum nigrum	black nightshade	California	WHITCOMB & TULLY 1979
Solanum tuberosum	potato	California	WHITCOMB & TULLY 1979; HAGEL & LANDIS 1974
Sonchus arvensis	perennial sowthistle	(laboratory) New York	KUNKEL 1926; WHITCOMB & TULLY 1979
Sonchus asper	prickly sowthistle	California	WHITCOMB & TULLY 1979

Latin Name	Common Name	Location	Reference
Fragaria x ananassa	garden strawberry	California, Canada	WHITCOMB & TULLY 1979
Gaillardia aristata	Gaillardia	(laboratory)	KUNKEL 1926
Gaillardia pulchella	roseing gaillardia	California	WHITCOMB & TULLY 1979
Galinsoga parviflora	smallflower galinsoga	New York	WHITCOMB & TULLY 1979
Gaura lindheimeri	white gaura	California	WHITCOMB & TULLY 1979
Geum chiloense	Geum	California	WHITCOMB & TULLY 1979
Gladiolus hybrid	gladiole	Maryland	WHITCOMB & TULLY 1979
Gloxinia		(laboratory)	KUNKEL 1926
Gnaphalium decurrens	California everlasting	California	WHITCOMB & TULLY 1979
Gnaphalium ramosissimum	pink everlasting	California	WHITCOMB & TULLY 1979
Gypsophila paniculata	baby's breath	(laboratory), California	KUNKEL 1926; WHITCOMB & TULLY 1979
Helenium autumnale	common sneezeweed	New York	WHITCOMB & TULLY 1979
Helenium latifolium	sneezeweed	Texas	WHITCOMB & TULLY 1979
Helenium nudiflorum	purplehead sneezeweed	New York	WHITCOMB & TULLY 1979
Helenium puberulum	rosilla	California	WHITCOMB & TULLY 1979
Helianthemum chamaecistus	rockrose	(laboratory)	WHITCOMB & TULLY 1979
Helianthus annuus	common sunflower	California	WHITCOMB & TULLY 1979
Helichrysum arenarium	strawflower	(laboratory)	KUNKEL 1926
Helichrysum bracteatum	strawflower	California	WHITCOMB & TULLY 1979
Hemizonia corumbosa	coast tarweed	California	WHITCOMB & TULLY 1979
Hordeum vulgare	barley	(laboratory)	CHIYKOWSKI 1991a
Ilysanthes dubia		California	WHITCOMB & TULLY 1979
Lactuca sativa	lettuce	(laboratory), Ontario, Minnesota, Manitoba, California, Ohio	KUNKEL 1926; McCLANAHAN 1963; MILLER & DELYZER 1960; SETIAWAN & RAGSDALE 1987; ZALOM 1981; LEE & ROBINSON 1958; NICHIPORICK 1965; WHITCOMB & TULLY 1979; MURRAL et al. 1996
Lactuca scariola var. integrata	prickly lettuce	California	WHITCOMB & TULLY 1979
Lactuca serriola	prickly lettuce	New York	WHITCOMB & TULLY 1979
Lactuca spp. *(altaica, canadensis, floridana, graminifolia, indica, perennis, muralis, raddeana, saligna, spicata, squarrosa, virosa)*	lettuce	USA	WHITCOMB & TULLY 1979
Lamium amplexicaule	dead henlt(nettle	California	WHITCOMB & TULLY 1979
Lavender	cultivated lavender	(laboratory)	KUNKEL 1926
Leohodon autumnalis	fall dandelion	New York	WHITCOMB & TULLY 1979
Limonium sinuatum	sea lavender	California	WHITCOMB & TULLY 1979
Limonium spp.	perennial statice	California	BAKER et al. 1983
Linaria bipartita	cloven-lip toadflax	California	WHITCOMB & TULLY 1979
Linaria californica	oldfield toadflax	California	WHITCOMB & TULLY 1979
Lobelia erinus var. compacta	edging lobelia	(laboratory)	WHITCOMB & TULLY 1979
Lycopersicon esculentum	tomato	California	WHITCOMB & TULLY 1979
Malva parviflora	little mallow	California	WHITCOMB & TULLY 1979
Malva rotundifolia	common mallow	California	WHITCOMB & TULLY 1979
Martynia		(laboratory)	KUNKEL 1926

Latin Name	Common Name	Location	Reference
Matricaria matricarioides	pineapple weed	Ontario	WHITCOMB & TULLY 1979
Matricaria suaveolens	pineapple weed	California	WHITCOMB & TULLY 1979
Medicago hispida	bur-clover	California	WHITCOMB & TULLY 1979
Mimulus cardinalis	scarlet monkey-flower	California	WHITCOMB & TULLY 1979
Mimulus guttatus	common monkey-flower	California	WHITCOMB & TULLY 1979
Mimulus luteus	monkey flower	(laboratory)	KUNKEL 1926
Monarda fistulosa	monarda	Alberta	HWANG et al. 1997c; WANG et al. 1998; KHADHAIR et al. 1997
Myosotis scorpioides	forget-me-not	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Nemesia		(laboratory)	KUNKEL 1926
Nemophila		(laboratory)	KUNKEL 1926
Nicotiana rustica	wild tobacco	(laboratory)	KUNKEL 1937; WHITCOMB & TULLY 1979
Nigella damascena	love-in-a-mist	California	WHITCOMB & TULLY 1979
Parthenium hysterophorus	Santa Maria	Texas	WHITCOMB & TULLY 1979
Pastinaca sativa	parsnip	New York	WHITCOMB & TULLY 1979
Petroselinum crispum	parsley	California	WHITCOMB & TULLY 1979
Petroselinum hortense	parsley	Alberta	KHADHAIR et al. 1998
Petunia x hybrida	garden petunia	California	WHITCOMB & TULLY 1979
Phlox drummondii	annual phlox	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Phlox paniculata		(laboratory)	KUNKEL 1926
Picris echioides	bristly oxtongue	California	WHITCOMB & TULLY 1979
Pimpinella anisum	anise	(laboratory)	KUNKEL 1926
Plantago major	great plantain	(laboratory) New York	KUNKEL 1926; WHITCOMB & TULLY 1979
Polygonum convolvulus	black bindweed	California	WHITCOMB & TULLY 1979
Portulaca		(laboratory)	KUNKEL 1926
Portulaca oleracea	purslane	(laboratory)	WHITCOMB & TULLY 1979
Primula elatior		(laboratory)	KUNKEL 1926
Primula polyantha	polyanthus primrose	California	WHITCOMB & TULLY 1979
Pyrrhopappus multicaulis	false dandelion	Texas	WHITCOMB & TULLY 1979
Ranunculus asiaticus	Persian buttercup	California	WHITCOMB & TULLY 1979
Reseda odorata	mignonette	(laboratory)	KUNKEL 1926
Rorippa curvisiliqua	western yellow cress	California	WHITCOMB & TULLY 1979
Rudbeckia hirta	hairy coneflower	New York	WHITCOMB & TULLY 1979
Rumex acetosa	sheep sorrel	California	WHITCOMB & TULLY 1979
Salpiglossis		(laboratory)	KUNKEL 1926
Salpiglossis sinuata	painted-tongue	California	WHITCOMB & TULLY 1979
Salvia azurea	azure sage	California	WHITCOMB & TULLY 1979
Satureia hortensis	summer savory	(laboratory)	KUNKEL 1926
Scabiosa atropurpurea	sweet scabious	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Schizanthus		(laboratory)	KUNKEL 1926
Scorzonera hispanica	black salsify	California	WHITCOMB & TULLY 1979
Senecio vulgaris	common groundsel	California	WHITCOMB & TULLY 1979
Silene pendula		(laboratory)	KUNKEL 1926
Solanum nigrum	black nightshade	California	WHITCOMB & TULLY 1979
Solanum tuberosum	potato	California	WHITCOMB & TULLY 1979; HAGEL & LANDIS 1974
Sonchus arvensis	perennial sowthistle	(laboratory) New York	KUNKEL 1926; WHITCOMB & TULLY 1979
Sonchus asper	prickly sowthistle	California	WHITCOMB & TULLY 1979

Latin Name	Common Name	Location	Reference
Sonchus oleraceus	common sowthistle	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Spergula arvensis	corn spurry	California	WHITCOMB & TULLY 1979
Spermolepis echinata		Texas	WHITCOMB & TULLY 1979
Spinacia oleracea	spinach	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Stellaria media	common chickweed	California	WHITCOMB & TULLY 1979
Tagetes erecta	Aztec marigold	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Tagetes patula	French marigold	California	WHITCOMB & TULLY 1979
Taraxacum officinale	common dandelion	(laboratory) Arkansas	KUNKEL 1926; WHITCOMB & TULLY 1979
Trachymene coerulea	blue-lace-flower	California	WHITCOMB & TULLY 1979
Tragopogon dubius	western salsify	Washington	WHITCOMB & TULLY 1979
Tragopogon porrifolius	oyster plant	(laboratory) Washington	KUNKEL 1926; WHITCOMB & TULLY 1979
Trifolium fragiferum	strawberry clover	California	WHITCOMB & TULLY 1979
Trifolium hybridum	alsike clover	California	WHITCOMB & TULLY 1979
Trifolium pratense	red clover	California	WHITCOMB & TULLY 1979
Trifolium repens	white clover	California	WHITCOMB & TULLY 1979
Triticum aestivum	wheat	(laboratory)	WHITCOMB & TULLY 1979
Tropaeolum majus	garden nasturtium	California	WHITCOMB & TULLY 1979
Urtica californica	nettle	(laboratory)	WHITCOMB & TULLY 1979
Verbesina encelioides	crownbeard	Texas	WHITCOMB & TULLY 1979
Veronica americana	American speedwell	California	WHITCOMB & TULLY 1979
Veronica buxbaumii	Byzantine speedwell	California	WHITCOMB & TULLY 1979
Vicia faba	broad bean	Alberta Manitoba Saskatchewan	WHITCOMB & TULLY 1979
Zinnia elegans	Zinnia	Manitoba Saskatchewan California	LEE & ROBINSON 1958; WHITCOMB & TULLY 1979

6 HOSTS OF "YELLOWS" DISEASES

As technology improves, the classification of plant diseases becomes more complex. Early in this century, scientists such as KUNKEL (1926) who did groundbreaking research on aster yellows did not really know much about the disease on the nuclear level. Aster yellows was referred to as a "virus-like" disease because it had virus-like symptoms and was known to be spread by insects, just like many plant viruses. A plant would be diagnosed with having aster yellows if it merely displayed symptoms classic to the disease and was shown to be transmittable by a known vector. Today, scientists have devised new systems for classifying phytoplasmas and similar organisms. However, these new systems have stricter requirements for phytoplasma identification and classification. A plant showing all the classic symptoms of aster yellows

cannot be scientifically diagnosed to have aster yellows unless identification is made on the molecular level.

For example, HWANG et al. (1997a) first observed purple coneflower (*Echinacea purpurea*) infected with a phytoplasma-induced yellows disease in Alberta in 1994-95. However, DNA analysis of phytoplasmas was not developed enough at this time to confirm that the phytoplasma did in fact belong in the aster yellows group. By 1997, KHADHAIR et al. was able to expressly confirm the diagnosis using more developed molecular techniques. However, not all reports of phytoplasma-induced yellows diseases have yet been confirmed and therefore cannot be included in Table 2. Table 3 is a listing of plants confirmed to have a 'yellows' phytoplasma disease, as well as plants that were only reported to have 'virus' symptoms (*ie.* WESTDAL et al. 1961).

Table 3 - List of 'Yellows' Plant Hosts, Grouped by Latin Name

Latin Name	Common Name	Location	Reference
Ammobium alatum	winged everlasting	Alberta	CHANG et al. 1992
Anthriscus cerefolium	curled chervil	Alberta	HWANG et al. 1998
Brassica chinensis	pak-choi	Alberta	CHANG et al. 1995
Calendula officinalis	pot marigold	Alberta	HWANG et al. 1997d
Carum carvi	caraway	Alberta Saskatchewan	HWANG et al. 1997b
Daucus carota	carrot	Oklahoma	ERRAMPALLI & FLETCHER 1991
Descurainia sophia	flixweed	Manitoba	WESTDAL et al. 1961
Echinacea angustifolia	Echinacea	Alberta	HWANG et al. 1997a
Goniolimon tataricum	German statice	Alberta	CHANG et al. 1996b
Hesperis matronalis	dam's violet/sweetrocket	Alberta	CHANG et al. 1996a
Lactuca sativa	lettuce	Oklahoma	ERRAMPALLI & FLETCHER 1991
Limonium sinuatum	annual statice	Alberta Michigan	CHANG et al. 1994; BAKER et al. 1983
Oenothera biennis	evening primrose	Alberta	HWANG et al. 1998
Senecio vulgaris	groundsel	Manitoba	WESTDAL et al. 1961
Valeriana officinalis	valerian	Alberta	HWANG et al. 1997d

It is important to note that many of the plants included in Table 2 were diagnosed before the development of the molecular techniques available today. In fact, nearly all of WHITCOMB & TULLY's (1979) citations were diagnosed based solely on symptom expression. Only *Taraxacum officinale, Vicia faba, Nicotania rustica* and *Spinacea oleracea* were diagnosed using electron microscopy. In 1926, KUNKEL would have taken BAKER et al.'s evidence that the MLO could be transmitted to healthy plants from diseased annual statice using the known vector of aster yellows, *Macrosteles fascifrons*, and declared that the disease was indeed aster yellows.

Latin Name	Common Name	Location	Reference
Sonchus oleraceus	common sowthistle	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Spergula arvensis	corn spurry	California	WHITCOMB & TULLY 1979
Spermolepis echinata		Texas	WHITCOMB & TULLY 1979
Spinacia oleracea	spinach	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Stellaria media	common chickweed	California	WHITCOMB & TULLY 1979
Tagetes erecta	Aztec marigold	(laboratory) California	KUNKEL 1926; WHITCOMB & TULLY 1979
Tagetes patula	French marigold	California	WHITCOMB & TULLY 1979
Taraxacum officinale	common dandelion	(laboratory) Arkansas	KUNKEL 1926; WHITCOMB & TULLY 1979
Trachymene coerulea	blue-lace-flower	California	WHITCOMB & TULLY 1979
Tragopogon dubius	western salsify	Washington	WHITCOMB & TULLY 1979
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Tropaeolum majus	garden nasturtium	California	WHITCOMB & TULLY 1979
Urtica californica	nettle	(laboratory)	WHITCOMB & TULLY 1979
Verbesina enceliodes	crownbeard	Texas	WHITCOMB & TULLY 1979
Veronica americana	American speedwell	California	WHITCOMB & TULLY 1979
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		Saskatchewan	
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However, by 1983, BAKER et al. needed stronger evidence than this to draw such a conclusion; thus, annual statice must appear in Table 3.

7 VECTOR HOSTS

7.1 Reported Hosts of the Six-Spotted Leafhopper (*Macrosteles fascifrons*)

Presumably, the hosts of aster yellows mentioned in Table 2 are also hosts of leafhoppers because these are the only known vectors of the disease (*pers. comm.* D. MAXWELL 1999). However, leafhoppers have been found on plant species that have not been reported to be hosts of aster yellows. It is possible that these plants have immunity and that the phytoplasma cannot survive and/or reproduce inside the plant; however, some of these plants such as alfalfa and potato have been hypothesized to be symptomless carriers of phytoplasma diseases (HWANG et al. 1996). It was long thought that cereals were immune to aster yellows (WESTDAL et al. 1961). However, it has since been proven that most cereals including wheat (WHITCOMB & TULLY 1979), rye (WESTDAL & RICHARDSON 1969), oats and barley (CHIYKOWSKI 1991a) can host the phytoplasma and provide inoculant for leafhoppers. There is much information available as to the food preferences of the six-spotted leafhopper, *M. fascifrons*. This is perhaps the most widely studied vector of aster yellows, probably due to the fact that it is polyphagus and causes damage to a wide variety of crops, whether physical damage or indirectly through the effects of disease.

Scientists in southwestern Ontario found *M. fascifrons* on oats, barley, rye and wheat in that order of preference (MILLER & DE LYZER 1960). However, once cereals began to ripen in early summer, leafhoppers would move to vegetables, ornamentals and other more succulent vegetation. After harvest of these vegetables, leafhoppers would return to cereals that had been fall-seeded, and here they would overwinter in the egg stage. It was also concluded that leafhoppers had no preference for winter wheat. Leafhoppers could be reared under artificial conditions on oats, barley, rye, wheat, aster, periwinkle, plantain, lettuce, carrot, celery, turnip, corn, chickweed, purslane, dandelion, potato, fleabane, and chrysanthemum.

WALLIT (1962) found that the six-spotted leafhopper preferred bindweed, carrot, celeriac, celery and endive in a sweep study of 35 plants (mostly vegetables). In Manitoba field studies,

LEE & ROBINSON (1958) showed that *M. fascifrons* preferred lettuce in June and July, and carrots in August, over aster, parsley and flax. However, McCLANAHAN (1963) found the highest number of *M. fascifrons* per plant on flax, wheat and rye, in that order of preference, and lower numbers on carrot, lettuce, oats, barley, dandelion, flixweed, prickly lettuce, curled dock, aster and onion.

HAGEL et al. (1973) found that *M. fascifrons* preferred ladino clover, although they were also found on barley, wheat, alsike and red clover, carrots and potatoes. It was thought that leafhoppers preferred ladino over the other clovers because it was in grazed pasture and therefore could not mature. Fewer leafhoppers were produced on ungrazed clover fields that were grown for seed. The most important breeding areas for the aster yellows leafhopper were pastures with alsike and/or ladino clover with pasture grasses, followed by ladino or alsike clover grown for seed. Other leafhopper hosts mentioned here were sweet corn, lawn grasses, rye, oats, field corn, *Erigeron* spp., ragweed (*Ambrosia* sp.), sugarbeet, bromegrass, alfalfa, dandelion, Canada wild lettuce (*Lactuca canadensis* L.), hedgemustard (*Sisymbrium altissimum* L.), common lambsquarters (*Chenopodium album* L.) and unidentified perennial grasses.

WESTDAL (1961) observed that cereals, in particular barley, were favoured by *M. fascifrons*. The plants he observed leafhoppers on included bluegrass, brome, wheat, fall rye, stinkweed, oats and millet. He isolated viruliferous leafhoppers from lettuce, stinkweed, prickly lettuce (*Lactuca scariola* var. *integrata*), flax and sunflower.

KUNKEL (1926) listed *Macrosteles fascifrons*'s favourite hosts as aster, lettuce, sow thistle, great ragweed (*Ambrosia trifida*), daisy fleabane (*Erigeron annuus*) and other Erigerons, English plantain (*Plantago lanceolata*), dandelion (*Taraxacum officinale*), wheat, oats, rye, barley, Calendula, *Ammobium alatum*, *Matricaria alba*, *Centaurea imperialis*, *Gaillardia grandiflora*, Moon Penny daisy (*Chrysanthemum leucanthemum*), and the African daisy (*Dimorphotheca aurantiaca*). It was stated that the leafhopper does not flourish on tobacco, potato, tomato, Schizanthus, peach, Begonia, and alsike clover. If favoured plants are unavailable, the leafhopper will also live and reproduce on corn, African marigold, milkweed (*Asclepias nivea*) and cosmos.

8 GEOGRAPHIC DISTRIBUTION OF ASTER YELLOWS

8.1 History of Severe Epidemics

In 1926, aster yellows was so serious in the United States that the cultivation of asters as an ornamental crop in many parts of the country had to be greatly reduced, if not abandoned. In the eastern states, 90 to 95 percent infection in aster fields was not uncommon. However, aster fields in certain areas remained uninfected (KUNKEL 1926).

In 1957 in Ontario, market gardeners growing lettuce, carrots and celery were forced to destroy hundreds of acres of these crops due to aster yellows. In the same year in Manitoba, vegetable crop losses were high; sunflower and flax losses were also severe (MILLER & DE LYZER 1960).

HWANG et al. (1997) reported that more than 30 percent of *Echinacea purpurea* and monarda plants in Brooks, Alberta were infected with aster yellows, as confirmed by KHADHAIR et al. (1997). Only 5 to 10 percent of plants showed symptoms in early May of 1994, but by fall the disease had spread to over 30 percent of the plants.

8.2 Aster Yellows Distribution in North America

Table 4 and Table 5 list Canadian provinces and U.S. states, respectively, that have had reports published regarding aster yellows. Specific locations reported in Canada include Brooks, Edmonton, Olds, Lac La Biche, Warwick and Bon Accord, Alberta; Outlook, Saskatchewan; and Portage la Prairie, Manitoba.

Table 4 - Canadian Provinces Reporting Aster Yellows

Province	Reference
Alberta	WHITCOMB & TULLY 1979; HWANG et al. 1997c; KHADHAIR et al. 1997 & 1998; WANG et al. 1998; HWANG et al. 1997c; CONN et al. 1993
Manitoba	WHITCOMB & TULLY 1979, HENNE 1970; WESTDAL et al. 1961; LEE & ROBINSON 1958; MARTIN et al. 1961
Ontario	WHITCOMB & TULLY 1979; McCLANAHAN 1963; MILLER & DE LYZER 1960; CHIYKOWSKI 1977 & 1978
P.E.I.	CONN et al. 1993
Quebec	ARCELIN & KUSHALAPPA 1991
Saskatchewan	WHITCOMB & TULLY 1979; PETRIE 1973; LEE & ROBINSON 1958
Canada (all provinces)	IMPERIAL MYCOLOGICAL INSTITUTE 1944

Table 5 - U.S. States Reporting Aster Yellows

State	Reference
Arkansas	WHITCOMB & TULLY 1979
California	WHITCOMB & TULLY 1979; BAKER et al. 1983
Colorado	WHITCOMB & TULLY 1979
Louisiana	WHITCOMB & TULLY 1979
Maryland	WHITCOMB & TULLY 1979
Michigan	BAKER et al. 1983; MULLER et al. 1973
Minnesota	SETIAWAN & RAGSDALE 1987; MURRAL et al. 1996; ZALOM 1981
New Jersey	KUNKEL 1937
New York	WHITCOMB & TULLY 1979; VERNON et al. 1942
North Dakota	MILLER et al. 1961
Ohio	MURRAL et al. 1996; HOY et al. 1992
Oklahoma	ERRAMPALLI & FLETCHER 1991
South Dakota	MILLER et al. 1961
Texas	WHITCOMB & TULLY 1979
Washington	WHITCOMB & TULLY 1979
Wisconsin	MAXWELL & MAXWELL 1998; MURRAL et al. 1996; STANOSZ & HEIMANN 1997; pers. comm. D. MAXWELL 1999
USA (upper midwestern)	ARCELIN & KUSHALAPPA 1991; SCHULTZ 1973; ZALOM 1981
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9 GEOGRAPHIC DISTRIBUTION OF LEAFHOPPERS

9.1 *Macrosteles fascifrons* Distribution in North America

Only detailed reports of *M. fascifrons* are included here because it is considered the major vector of aster yellows. See sections 10.2 to 10.27 for geographical distributions of other leafhopper species.

There is some confusion as to whether *M. fascifrons* is present in Europe. LEE et al. (1998) reported a European distribution; however, NEILSON (1968) stressed that any reports from Europe, Asia and Oriental regions are incorrect. NEILSON reports a widespread United States distribution of *M. fascifrons*, as shown in Table 7. He also included reports from Mexico and Puerto Rico. In 1926, KUNKEL reported that *M. fascifrons* was present from Alaska to the southernmost borders of the United States. He also stated that this insect was common throughout Europe and Japan, and probably the Orient. Table 6 and Table 7, respectively, list Canadian provinces and U.S. states reporting *M. fascifrons*.

Table 6 - Canadian Provinces Reporting the Six-Spotted Leafhopper

Province	Reference
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Manitoba	CHIYKOWSKI & CHAPMAN 1956; NEILSON 1968

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Northwest Territories	NEILSON 1968
Nova Scotia	NEILSON 1968
Ontario	CHIYKOWSKI & CHAPMAN 1956; NEILSON 1968
Prairies (widespread)	MARTIN et al. 1961
Quebec	NEILSON 1968
Saskatchewan	NEILSON 1968

Table 7 - U.S. States Reporting the Six-Spotted Leafhopper

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Alabama	NEILSON 1968
Alaska	NEILSON 1968
Arizona	NEILSON 1968
Arkansas	CHIYKOWSKI & CHAPMAN 1956; NEILSON 1968
California	NEILSON 1968
Colorado	WALLIS 1962; NEILSON 1968
Connecticut	NEILSON 1968
Florida	NEILSON 1968
Georgia	NEILSON 1968
Idaho	NEILSON 1968
Illinois	NEILSON 1968
Indiana	NEILSON 1968
Iowa	NEILSON 1968
Kansas	WALLIS 1962; NEILSON 1968
Louisiana	CHIYKOWSKI & CHAPMAN 1956; NEILSON 1968
Maine	NEILSON 1968
Maryland	NEILSON 1968
Massachusetts	NEILSON 1968
Michigan	NEILSON 1968
Minnesota	NEILSON 1968
Mississippi	NEILSON 1968
Missouri	CHIYKOWSKI & CHAPMAN 1956; NEILSON 1968
Montana	WALLIS 1962; NEILSON 1968
Nebraska	WALLIS 1962; NEILSON 1968
Nevada	NEILSON 1968
New Hampshire	NEILSON 1968
New Mexico	NEILSON 1968
New York	NEILSON 1968
North Carolina	NEILSON 1968
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Pennsylvania	NEILSON 1968
South Dakota	WALLIS 1962; NEILSON 1968
Tennessee	NEILSON 1968
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Utah	NEILSON 1968
Vermont	NEILSON 1968
Virginia	NEILSON 1968
Washington	HAGEL et al. 1973; NEILSON 1968
Wyoming	WALLIS 1962; NEILSON 1968
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Yukon	NEILSON 1968

9.2 Long Distance Migration of *M. fascifrons*

As early as 1958, researchers suspected a migration of *M. fascifrons* into Manitoba (LEE & ROBINSON 1958). Leafhoppers could only overwinter in the egg stage, but adults were present in large numbers for weeks before nymphs were found. Records of southerly wind duration and speed supported the migration theory, matching dates of influxes.

From 1954 until 1964, researchers kept track of the earliest spring influx of *M. fascifrons* into Manitoba (NICHIPORICK 1965). Over the 10 years these dates ranged from as early as May 3 to as late as May 29. In 3 of the 10 years there were large increases in leafhopper populations; these population explosions occurred anywhere from 2 to 5 weeks after the first influx. NICHIPORICK calculated trajectories to determine the source of influxes and found the main sources to be North and South Dakota, Nebraska and Kansas. It was thought that leafhoppers left these states to migrate as the crops they had developed on began to mature. Southerly winds were reportedly frequent enough to aid insect dispersal and migration. Through tests in June of 1957, NICHIPORICK estimated that 1 in 12 leafhoppers in the field was viruliferous.

WESTDAL (1961) showed that *M. fascifrons* overwinters in Manitoba only in the egg stage. Migrants arrived in substantial numbers in mid-May, carried on strong south winds. Mortality among migrants was high by late June and early July. Most of the local population was the result of eggs laid by migrants and not eggs laid by leafhoppers that had overwintered in Manitoba in the egg stage. This new local population began to appear in late June and the combined populations peaked in mid-August. The percentage of viruliferous leafhoppers was 1 percent or less throughout the season and was highest in the spring migrant population. However, the highest transmission rates occurred in mid-August with peak leafhopper numbers.

CHIYKOWSKI & CHAPMAN (1965) reported that *M. fascifrons* migrates passively with air currents that have temperatures above 60°F, landing and taking shelter when cold winds blow in from the north, east or west. Major source areas for migrants include the following states: Texas, Oklahoma, Louisiana, Arkansas, Kansas and Missouri. The main migration path through northern states is north-by-northwesterly, and the path widens from source states through to Canada.

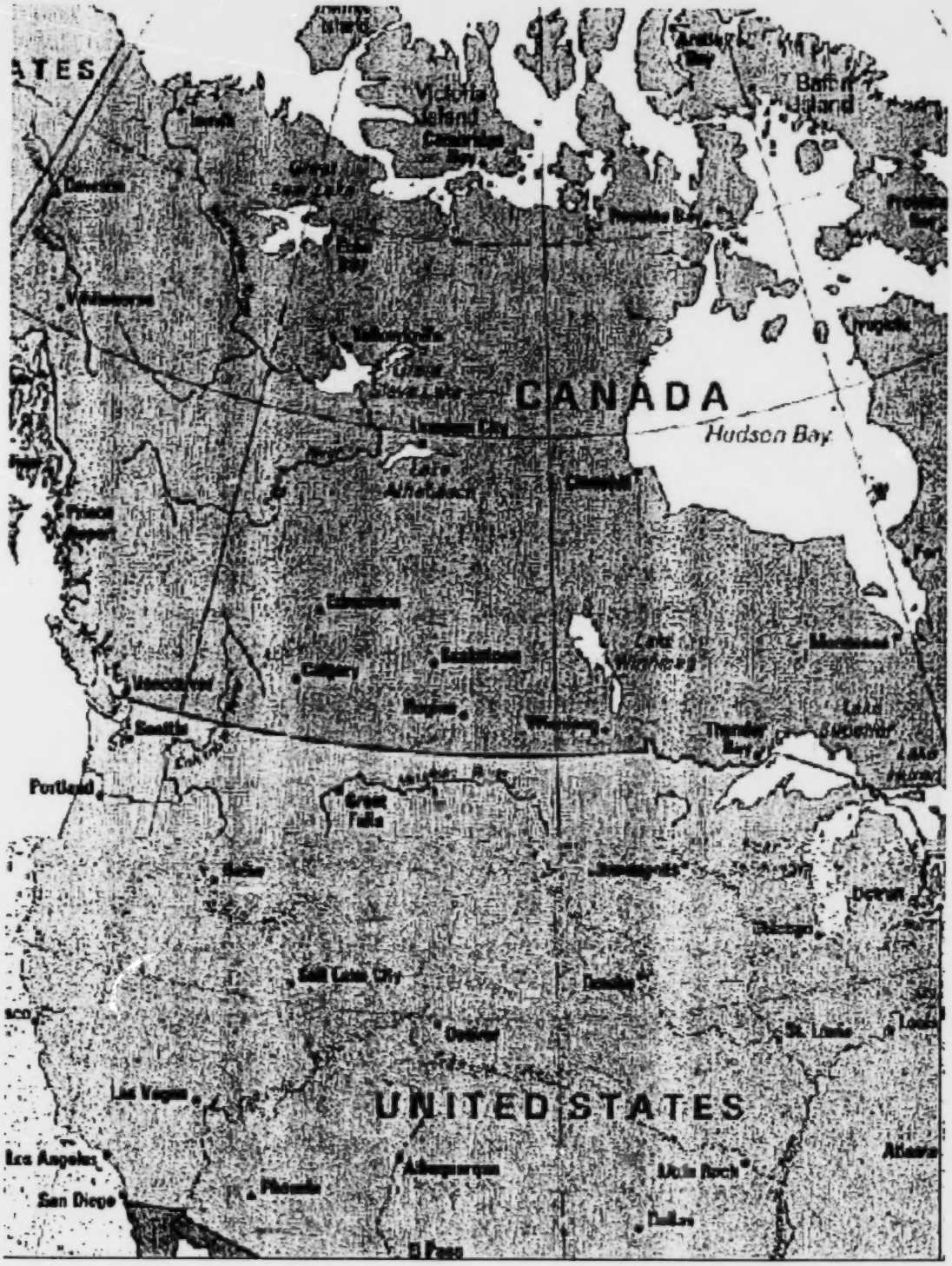
PETERSON (1973) reported that some leafhoppers migrating to Minnesota in the spring could transmit aster yellows within a week of arrival. This evidence suggested that a percentage of migrants were undergoing the latent period on their flight northward and were carrying aster yellows from a source along their trajectory rather than local aster yellows. Figure 2 is a map of North America for reference purposes (from World Atlas, http://micron.me.tuns.ca/~gang/atlas/northamerica.html).

10 VECTORS

FLETCHER et al. (1998) states that to date, the only known vectors of mollicutes, which include phytoplasmas and spiroplasmas, are phloem-feeding leafhoppers (Insecta: Homoptera; Auchenorryhncha; Cicadellidae) and a small number of psyllid vectors in the suborder Sternorrhyncha. LEE et al. (1998) includes planthoppers (Fulgoroidea) in addition to leafhoppers (Cicadellidae) as vectors of phytoplasmas in nature. However, only leafhoppers are known to transmit the aster yellows phytoplasma (*pers. comm.* D. MAXWELL 1999). Once a leafhopper ingests the phytoplasma through feeding from the phloem of an infected plant, the organism multiplies in the body of the leafhopper and the insect remains infected for its lifetime (FLETCHER et al. 1998). The period from leafhopper acquisition of the phytoplasma to the point where the organism multiplies to a level high enough to be transmitted to a healthy plant by the leafhopper (the leafhopper becomes inoculative) is known as the latent period. The latent period can take 3-4 weeks or more. DOSHEIDT (1997) and KUNKEL (1926) defined the latent period as being 10 days or longer while KIRKPATRICK (1989) said it ranged from 2-6 weeks. KIRKPATRICK also noted that this latent period for mollicutes was interesting considering that beetles and aphids transmit viruses most efficiently immediately after acquisition.

Phytoplasmas differ in their insect vector specificity. A phytoplasma is said to have a low insect vector specificity when it can be transmitted by several different insect species. One example is the California aster yellows phytoplasma. It can be transmitted by 24 species of leafhoppers (LEE et al. 1998).

Figure 2 - Map of North America



There are 27 known leafhopper vectors of the aster yellows phytoplasma in North America. These are listed in Table 8 according to the strains they transmit. Sections 10.1 to 10.27 describe individual leafhoppers in North America reported to be vectors of aster yellows, their feeding habits (polyphagus or specific), and their geographical distribution.

Table 8 - List of Vectors According to Strain Transmitted

Vector	Western Strain	Eastern Strain
Acinopterus reticulata	✓	
Aphrodes bicincta		✓
Athysanus argentarius		✓
Chlorotettix similis	✓	
Colladonus flavocapitata	✓	
Colladonus geminata	✓	
Colladonus holmesi	✓	
Colladonus intricata	✓	
Colladonus kirkaldyi	✓	
Colladonus montanus	✓	
Colladonus rupinata	✓	
Elymana sulphurella		✓
Endria inimicus	✓	
Eusecelis variegatus	✓	
Fieberiella florii	✓	
Gyponana hasta	✓	
Macrosteles fascifrons	✓	✓
Paraphlepsius apertinus	✓	
Scaphytopius acutus	✓	
Scaphytopius delongi	✓	
Scaphytopius irroratus	✓	
Texananus incurvatus	✓	
Texananus lathropi	✓	
Texananus latipex	✓	
Texananus oregonus	✓	
Texananus pergradus	✓	
Texananus spatulatus	✓	

10.1 Six-Spotted Leafhopper (*Macrosteles fascifrons* (Stål))

In 1926, KUNKEL tested several insect species as transmitters of aster yellows. The insects he studied included: green aster leafhopper, *Empoasca flavescens* (Fab); tarnished plant bug, *Lygus pratensis* L.; clover leafhopper, *Agallia sanguinolenta* (Prov); peach aphid, *Myzus persicae* (Sulz); greenhouse thrip, *Thrips tabaci* (Lind); white fly, *Trialeurodes vaporariorum* W.; red

mite, *Tetranychus telarius* L.; leafhopper, *Graphocephala coccinea* (Forst); potato leafhopper, *Empoasca flavescens* (Fab); and six-spotted leafhopper, *Cicadula sexnotata* (Fall) (=*Macrosteles fascifrons* (Stål)). Most of these insects had been identified from infected aster plots in New York. In experiments using asters and sometimes calendula, KUNKEL was only able to identify *M. fascifrons* as a vector. All other insects failed to readily transmit the disease.

Today, the principal vector and distributor of aster yellows is considered to be *Macrosteles fascifrons* (SETIAWAN & RAGSDALE 1987). Unlike *Macrosteles laevis*, the southern Europe vector of European aster yellows, which cannot transmit either strain of North American aster yellows, *M. fascifrons* can transmit European aster yellows and both North American strains of the disease (16Sr-A and –B). *M. fascifrons* can also transmit clover phyllody (16SrI-C) and clover proliferation (16SrVI-A) phytoplasmas in nature (LEE et al. 1998). The polyphagus nature of the leafhopper contributes to its status as the principal vector of this disease. It is also widely distributed in North America. In 1977, CHIYKOWSKI reported that *M. fascifrons* was able to transmit CAYA (the celery-infecting strain of aster yellows) with a transmission rate of 87 percent. NEILSON (1968) states that in addition to being the most important vector of both eastern and western North American aster yellows, *M. fascifrons* has been reported to vector little cherry virus in British Columbia, and oat blue dwarf virus, clover phyllody virus and clover proliferation virus in Canada.

Macrosteles quadrilineatus is a common migrant to Ohio vegetable farms from southern and western states, bringing with it the aster yellows phytoplasma (MURRAL et al. 1996). In Wisconsin, predictions of aster yellows severity is based on migration patterns and infectivity levels of *M. quadrilineatus* populations moving into the state from south central states (MAHR et al. 1993). One of the co-authors of MURRAL et al. (1996) reports that the Entomological Society of America has renamed *M. fascifrons* as *M. quadrilineatus* and that they are the same species (HOY *pers. comm.* 1999).

10.1.1 Previous Names of *M. fascifrons*

M. fascifrons (Stål) has been previously known by many names, including the following:

- *Cicadula quadrilineatus* (Forbes 1885) (pers. comm. BRAUN 1999)
- *Cicadula sexnotata* (Harrington 1892) (NEILSON 1968)
- *Cicadula pallida* (Osborn 1915) (pers. comm. BRAUN 1999)

- *Macrosteles wilburi* (Dorst 1937) (pers. comm. BRAUN 1999)
- *Macrosteles scriptus* (Dorst 1937) (pers. comm. BRAUN 1999)
- *Macrosteles divisus* (Smith 1957) (NEILSON 1968)
- *Cicadula divisa* (WALLIS 1962)

The leafhopper's name has also been misspelled, for example, *Cicadula fascufrons* (Mitsuhashi 1909) and *Cicadula fasciifrons* (Clausen 1931) (*pers. comm.* BRAUN 1999). For ease of reading, all references to any of these names by authors cited in this paper have been changed to read *Macrosteles fascifrons*.

10.2 *Aphrodes bicincta* (Shrank)

A common polyphagus vector of North American aster yellows (16SrI-A) is *Aphrodes bicincta*. In nature this insect also transmits European aster yellows, clover phyllody (16SrI-C), strawberry green petal (16SrI-C) and clover yellow edge (16SrIII-B). Its geographical distribution covers both North America and Europe (LEE et al. 1998). CHIYKOWSKI (1977) reported that *A. bicincta* was widely distributed through most Canadian provinces. In the laboratory, the leafhopper could transmit the celery-infecting strain of aster yellows (CAYA) and over 80% of individuals in a population became inoculative. The average incubation period in this vector was 43.9 days – much longer than that of *M. fascifrons'* 25.6 days, although both vectors transmitted the disease equally well (transmission rates of over 80%). However, as *A. bicincta* aged, transmission rates became inconsistent, although some individuals remained capable of transmitting 5-6 months after acquisition of the phytoplasma. CHIYKOWSKI also noted that nymphs are green and slow-moving, feeding near ground level while adults are straw-coloured and easily disturbed from plants. Thus, this species is easily missed in sweep net collections. As a vector of clover phyllody and clover yellow edge, *Aphrodes bicincta*, although a polyphagus feeder, has an obvious clover preference; however, CHIYKOWSKI (1977) found this insect transmits aster yellows from aster and celery just as efficiently as *M. fascifrons*.

10.3 *Athysanus argentarius* (Metc)

In 1979, CHIYKOWSKI tested this leafhopper for its ability to transmit the celery-infecting strain of aster yellows (CAYA). This insect was introduced from Europe and was first noticed in Canada in 1940 in Ontario. A large grass-feeding species, it became very common in southern Ontario and Quebec by 1956. By 1966 it had been reported in Manitoba, and became a

commonly collected species by 1969. The insect was reported as early as 1946 in Maine, Massachusetts, New Hampshire and Vermont. Although the insect's natural hosts are grass species, CHIYKOWSKI found that the leafhopper survived equally well on aster infected with CAYA. It is interesting to note that survival was very poor on healthy aster plants. In a population of *A. argentarius*, only about 40% of individuals in a population could transmit CAYA.

CHIYKOWSKI (1979) reported the following hosts in Ontario and Manitoba for the leafhopper *Athysanus argentarius*: brome (*Bromus inermis*) and lawn grass (probably *Poa pratensis*). Insects confined to the following cereals and grasses in the field used these plants to deposit eggs: brome (*B. inermis*), Italian rye grass (*Lolium multiflorum*), wheat (*Triticum durum*), oats (*Avena byzantina*) and barley (Hordeum vulgare). The insect could also survive for a time on *Agropyron repens* and healthy asters. However, when compared to barley and *A. repens*, the leafhopper had equal or better survival on aster infected with CAYA.

10.4 *Endria inimicus* (Say)

CHIYKOWSKI (1979) indicates that this aster yellows vector feeds only on grasses in nature. This leafhopper has a wide distribution in the U.S.A. and is also common to British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Quebec (NEILSON 1968). Bluegrass is a preferred host, but the leafhopper is also found on timothy, wheat, oats, corn, millet, rye, clover, alfalfa, smooth brome and orchardgrass. In addition to vectoring western aster yellows the species transmits striate mosaic virus of wheat and other grains. In tests, leafhoppers could transmit aster yellows from celery to barley and wheat with minimum latent periods of 13 to 25 days. NEILSON considered *E. inimicus* an important vector of striate mosaic virus and if migratory, potentially important in the spread of western aster yellows.

10.5 *Elymana sulphurella* (Zett)

In a population of *E. sulphurella*, approximately 40 percent of individuals in a population were capable of transmitting CAYA. Also known by the name *E. virescens* (F.), this leafhopper is one of the aster yellows vectors to feed only on grasses in nature (CHIYKOWSKI 1979).

10.6 *Acinopterus reticulata* (Fabricius)

LEE et al. (1998) states that the geographical distribution of *A. reticulata* includes North America only. This polyphagus vector can transmit both California aster yellows (16SrI-B) and western X-disease (16SrIII-A). NEILSON (1968) indicates geographical distribution to include Mexico and Central America, West Indies and parts of South America in addition to Washington, California, Arizona and the southwestern United States. *A. reticulata* prefers legumes, but in studies could transmit western aster yellows to onion, aster and celery. Between aster and celery, transmission was always higher to celery (29.8 to 51.9% vs. 9.1 to 18.7%). Latent period minimums were 11 to 26 days, but 'virus' retention was poor overall. NEILSON believed this vector to be of some importance in California, and potentially important elsewhere.

Acinopterus reticulata has been reported on alfalfa (*Medicago sativa*), Spanish clover (*Lotus purshianus*), wild licorice (*Glycyrrhiza lepidota*), ladino clover (*Trifolium repens*), and also weeds, grasses, and pastures including *Bidens pilosa* (NEILSON 1968).

10.7 *Colladonus geminata* (Van Duzee)

LEE et al. (1998) states that this leafhopper inhabits North America only. This polyphagus vector can transmit both California aster yellows (16SrI-B) and western X-disease (16SrIII-A). NEILSON (1968) reports the principal hosts to be alfalfa and clover, although *C. geminata* has been collected from perennial delphinium and reared on *Chenopodium murale*, *Euphorbia peplus*, peach and celery. Geographical distribution includes California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming, British Columbia and the west cost of northern Mexico. Aster yellows transmission was 92 percent from naturally infected delphiniums to delphinium seedlings, but poor or no transmission was obtained to celery and aster. The species exhibited a latent period of 18 to 36 days.

10.8 *Fieberiella florii* (Stål)

This polyphagus leafhopper is capable of transmitting California aster yellows (16SrI-B) as well as both western and eastern X-disease (16SrIII-A) (LEE et al. 1998). LEE et al. purports the distribution to be North America only; however, NEILSON (1968) reports a wide distribution of *F. florii*, including Europe, the Near East, western Russia, the United States and Canada. The

insect was apparently introduced into North American from Europe. Eggs have been found on plum imported from France. NEILSON indicates that this leafhopper is an incidental vector of aster yellows and is much more important in the spread of yellow leaf roll virus in California.

Fieberiella florii has been collected from ornamentals such as California privet (*Ligustrum ovalifolium*), a hedge (*L. vulgare* fma. *nanum*), myrtle (*Myrtus communis*) and *Cotoneaster pannosa*. Canadian hosts include plum, currant, sour cherry, privet and spirea. Other hosts include sweet cherry, alfalfa, peach, sweetclover and pyracantha shrubs (NEILSON 1968).

10.9 *Gyponana hasta* (Delong)

Although not considered to be an important vector of aster yellows, this polyphagus leafhopper was shown to be able to transmit the western strain of North American aster yellows from celery to aster and celery (NEILSON 1968). The latent period ranged from 19 to 35 days and the insect could retain the 'virus' for 11 to 46 days. The study indicated that after the first inoculation, most adults lost the ability to transmit aster yellows. Plant hosts are listed as alfalfa, pasture celery, weeds and cherry and the species was mostly common in the western United States (Arizona and California especially).

The western U.S.A. leafhopper, *Gyponana hasta*, has been collected from alfalfa, *Rhus trilobata*, pasture, *Artemisia vulgaris*, *Trifolium repens*, celery, weeds and sweet and bitter cherries. As of 1968, it was not considered an important vector of aster yellows (NEILSON 1968).

10.10 *Scaphytopius irroratus* (Van Duzee)

Scaphytopius irroratus is a leafhopper species occuring in the southwestern United States, but at the time of publication (1968), NEILSON did not consider this insect important as a vector of aster yellows in California. Nymphs raised on celery infected with the western strain of aster yellows infected celery and aster. Only males could transmit the 'virus', and transmission rates ranged from 10 to 19 percent. Males retained the 'virus' for only 15 days. This species is polyphagus.

Considered to be a poor vector, *Scaphytopius irroratus* has been collected in the southwestern states on *Ambrosia* sp., *Eysenhardtia texana*, *Amaranthus* sp., *Heterotheca subaxillaris*, alfalfa,

wild licorice (*Glycyrrhiza lepidota*), mountain grape (*Vitis rupestris*), California blackberry (*Rubus vitifollius*), and has been reared on celery (NEILSON 1968).

10.11 *Scaphytopius delongi* (Young)

Only known in California, this leafhopper species has been collected from pasture grasses and weeds. Also known by the name *Cloanthanus dubius* (Van Duzee), insects could be reared on celery and were shown to be vectors of the western strain of aster yellows. Only 13 percent of the population could transmit the 'virus', and males could transmit with an effectiveness of 23 to 47 percent. Single adults could retain the disease from 1 to 29 days. Only celery was shown to be infected by inoculative insects, while asters remained healthy. NEILSON (1968) considered this vector to be of incidental importance in aster yellows transmission in California.

10.12 *Colladonus montanus* (Van Duzee)

Widely distributed in western U.S.A. and Canada, this species is polyphagus and is hosted by numerous plants such as delphinium, onion, *Eremocarpus setigerus* and *Lotus salsuginosus*. This leafhopper can transmit western aster yellows (16SrI-B), western X-disease (16SrIII-A) and yellow leaf roll strain of western X-disease (NEILSON 1968; LEE et al. 1998). Transmission rates were higher on celery (26.1%) than on aster (2.9%). The species easily transmitted from naturally infected delphinium and annual larkspur to celery. NEILSON considered this vector very important in the spread of western aster yellows to perennial delphinium, but unimportant in the spread of western X-disease because of low transmission efficiency. *C. montanus* was first reported as a vector of aster yellows under the name *Thamnotettix montanus*.

10.13 *Scaphytopius acutus* (Say)

Scaphytopius acutus (=*Platymoideus acutus* Say, *Scphytopius* (*Cloanthanus*) *dubius* Van Duzee) is widespread in Canada and the United States, except along the Pacific Coast. It has been reported in Nova Scotia, P.E.I., New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia in Canada. In the U.S., it has been reported in many central and eastern states, as well as Washington, Oregon and Utah. This is a polyphagus species which has been reported on numerous plant hosts. In addition to transmitting the western strain of North American aster yellows, *S. acutus* also vectors alfalfa witches' broom, western and eastern

X-diseases, little cherry virus in British Columbia, and clover phyllody in eastern Canada (NEILSON 1968). LEE et al. (1998) reports *S. acutus* as a vector of both California aster yellows (16SrI-B) and western X-disease (16SrIII-A). In the laboratory, the insect transmitted western aster yellows from aster and periwinkle to healthy aster, periwinkle and ladino clover. The minimum latent period was 21 to 26 days (NEILSON 1968). In general terms of 'virus' disease transmission, NEILSON considered this species to be very important.

S. acutus is common to most of North America. In Washington, it prefers alfalfa (*Medicago*), but has also been reported to feed generally on grasses and weeds. The species could be reared on ladino clover and breed on strawberry. Insects will also feed on the following:

- sticky laurel (*Ceanothus velutinus*)
- *Spirea* sp.
- thistle (*Cirsium*)
- balsam poplar (*Populus balsamifera*)
- wild rose
- willow
- Oregon grape (*Berberis* sp.)
- peach
- sweet cherry
- trefoil (*Lotus*)
- red clover (*Trifolium*)
- sweetclover (*Melilotus*)
- sheep sorrel (*Rumex acetosella*)
- chickweed (*Stellaria*)
- apple
- plum
- pear
- chokecherry
- wild black cherry
- wild plum
- sumac

10.14 <u>*Colladonus holmesi* (Bliven)</u>

This polyphagus leafhopper prefers trees and shrubs such as the wild currant. It has been reported in the western United States, specifically California and Idaho. Transmission tests (reported erroneously under the name *C. flavocapitatus*) indicated *C. holmesi* could transmit the western strain of aster yellows from celery to celery after 11 to 17 day feeding periods on diseased plants. NEILSON (1968) recommended further transmission tests because of confusion in species identification in previous experiments.

C. holmesi has been collected from redwood (*Sequoia sempervirens*), *Arctostaphylos manzanita*, *A. tomentosa*, *A. andersonii*, wild gooseberry (*Ribes* sp.), *R. roezli* and wild currant (*R. cereum*) (NEILSON 1968).

10.15 *Colladonus intricata* (Ball)

NEILSON (1968) indicated that this species was known only in California. Little was known at this time about the biology, including feeding preferences, of this species. Transmission of the western strain of aster yellows was effected from celery to celery, but with only about 25% transmission effectiveness. This species was not considered important in the spread of aster yellows in California. *C. intricata* was first reported as a vector of aster yellows under the name *Friscananus intricatus* (Ball).

C. intricata was collected from monkeyflower (*Diplacus aurantiacus*), bracken (*Pteridium aquilinum* var. *lanuginosum*), *Ceanothus thyrsiflorus* and *Arctostaphylos manzanita* (NEILSON 1968).

10.16 *Colladonus kirkaldyi* (Ball)

This leafhopper is distributed in California and Mexico. NEILSON (1968) suggested its natural host may be California sagebrush (*Artemisia californica*), but little else was known about its biology. An inefficient vector of western aster yellows, insects fed for 66 days on diseased celery and only infected 2 of 7 healthy plants. *C. kirkaldyi* was first reported as a vector of aster yellows under the name *Idiodonus kirkaldyi* (Ball).

10.17 *Colladonus rupinata* (Ball)

Only known from California, *C. rupinata* has been collected from bracken (*Pteridium aquilinum* var. *lanuginosum*), and monkeyflower (*Diplacus aurantiacus*). This species exhibited 29 percent efficiency in transmitting the western strain of aster yellows from bracken to celery and from celery to celery. Transmission was unsuccessful using asters, and NEILSON (1968) did not consider *C. rupinata* an important vector in California. *C. rupinata* was first reported as a vector of aster yellows under the names *Friscananus rupinatus* and *Friscananus rupinatus* var. *brunneus*.

10.18 *Colladonus flavocapitata* (Van Duzee)

This species has been collected from California blackberry (*Rubus vitifolius*), bush lupine (*Lupinus arboreus*) monkeyflower (*Diplacus aurantiacus*), bracken (*Pteridium aquilinum* var.

lanuginosum, Allepo pine (*Pinus halepensis*) and Japanese ivy (*Parthenocissus tricuspidata*). Geographical distribution covers western North America, including California, Colorado, Oregon, Utah, Washington, Alberta, British Columbia and Alaska. Although species identification was questionable, insects could transmit western aster yellows from celery to celery (22 to 69% transmission) and from aster to aster (0 to 20% transmission). NEILSON (1968) recommended further transmission studies with certain species identification. *C. flavocapitata* was first reported as a vector of aster yellows under the name *Colladonus commissus*.

10.19 *Paraphlepsius apertinus* (Osborn & Lathrop)

P. apertinus has been reported from western U.S.A. and Canada, including California, Oregon, Washington, southern British Columbia, and mountain areas of Alberta. NEILSON (1968) did not know much about the biology of this species, but it had been reported on the following host plants: alfalfa, cocklebur (*Xanthium canadense*), ladino clover (*Trifolium repens*), wild licorice (*Glycyrrhiza lepidota*), burclover (*Medicago hispida*), annual yellow clover (*Melilotus indica*) and common foxtail (*Hordeum murinum*). NEILSON considered this vector potentially important in the spread of western aster yellows and reported 20 to 100 percent transmission effectiveness from celery to celery.

10.20 *Texananus pergradus* (DeLong)

This species has been reported in the southwestern states of Oregon, California, Utah, Colorado, Arizona, New Mexico and Texas, and also Mexico. Limited plant hosts have been reported; these include annual yellow sweetclover, annual burweed (*Franseria acanthicarpa*), *Lotus* sp. and pasture vegetation. Adults could live longer on celery infected with aster yellows (24 days) than healthy celery (4.8 to 11.6 days). *T. pergradus* could transmit western aster yellows, but with very poor transmission efficiency (NEILSON 1968).

10.21 *Texananus lathropi* (Baker)

T. lathropi has been collected from pasture vegetation, burclover, wild pea (*Lathyrus bolanderi*), *Thermopsis macrophylla*, tree lupine (*Lupinus arboreus*) and puncture vine (*Tribulus terrestris*). Geographical distribution is restricted to the western U.S.A., including Oregon, Nevada,

California and Idaho. Adults could also live longer on diseased celery; survival on aster yellows infected plants was three times higher than on healthy celery. Transmission of western aster yellows in celery was only about 16 percent, but even less in aster. NEILSON (1968) did not consider this leafhopper an important vector of aster yellows.

10.22 *Texananus latipex* (DeLong)

There was some debate in 1968 as to the geographical distribution of this species. It was reported to be widespread in the United States, including Washington, Montana, North Dakota, Oregon, Idaho, Wyoming, California, Nevada, Utah, Colorado, Arizona, New Mexico and Texas. However, there were conflicting reports about distribution in British Columbia and Mexico. Plant hosts include pasture vegetation, spiny clotbur (*Xanthium spinosum*), alfalfa, grasses, redstem filaree, bermudagrass (*Cynodon dactylon*) and inland salt grass (*Distichlis stricta*). NEILSON (1968) did not consider this species to be an important vector of aster yellows in California because the insects did not have a preference for celery. Reported transmission effectiveness of western aster yellows in celery ranged from 18 to 32 percent.

10.23 *Texananus spatulatus* (Van Duzee)

This leafhopper has a wide distribution from the western United States to Mexico and the West Indies, including California, Colorado, Kansas, Texas, Montana, Utah, Nevada, New Mexico, Arizona and Oklahoma. Limited plant hosts reported include pasture vegetation, rough pigweed (*Amaranthus retroflexus*, puncture vine, redstem filaree (*Erodium cicutarium*), whitestem filaree (*E. moschatum*), alfalfa and nettleleaf goosefoot (*Chenopodium murale*). Insects were more efficient transmitting western aster yellows to and from celery (29 to 89%) than aster. Longevity was again improved on diseased *versus* healthy plants. Insects retained the virus for significant periods of time (around 90 days) and NEILSON (1968) considered this vector of potential importance.

10.24 *Texananus oregonus* (Ball)

Western Canada and the U.S.A. is the range of distribution for this species. It has been reported in Washington, Oregon, California, Arizona, British Columbia and Mexico. Wild pea, burclover, wild honeysuckle and pasture grasses make up the list of known plant hosts.

Transmission effectiveness of western aster yellows to celery was about 40 percent, but NEILSON (1968) did not consider this species an important vector in California.

10.25 *Chlorotettix similis* (DeLong)

Only California is mentioned, but this species is apparently distributed in the western United States. Only *Artemisia vulgaris* has been reported as a host of *C. similis*. NEILSON (1968) did not consider this species to be important in the spread of western aster yellows. Transmission efficiency to and from celery is reported as 23 percent.

10.26 *Eusecelis variegatus* (Kirschbaum)

This species has a more global distribution, from Europe to Asia and northern Africa. It has been reported in France, Siberia, Caucasia, Azores, the Canary Islands and the Mediterranean. The species was apparently introduced in North America and occurs is California, Oregon, Utah and Washington. In the United States, these leafhoppers are hosted by grassy alfalfa, celery, common dandelion, endive, lettuce, red beet, Swiss chard, spinach, *Artemisia vulgaris*, narrowleaf sage, rosemary and sweet marjoram. Insects could be reared on barley and diseased aster, but not healthy aster. *E. variegatus* has a transmission efficiency for western aster yellows of over 75 percent in celery. No insects infected aster from diseased celery. NEILSON (1968) did not consider this species to be important in vectoring aster yellows. *E. variegatus* was first reported as a vector of aster yellows under the name *Euscelis maculipennis* (Delong & Davidson).

10.27 *Texananus incurvatus*

This species has been reported from the southwestern states of Arizona, California and New Mexico, and also from northwestern Mexico. Only alkali heath (*Frankenia grandifolia*) is reported as a natural host, but insects were reared easily on celery. Transmission efficiency of western aster yellows from diseased celery was 26 percent to healthy celery, and 1 percent to healthy aster. NEILSON (1968) considered this vector (=*Excultanus incurvatus*) of potential importance in California.

11 OTHER DISEASES OF INTEREST

Lettuce infectious yellows virus (LIYV) is transmitted by the sweetpotato whitefly (*Bemisia tabaci*) (DUFFUS et al. 1986). In 1981 in California and Arizona, crops losses due to LIYV were high in lettuce, sugarbeets, cantaloupe, watermelon, other melons and squash. Lettuce and sugarbeet crops had infection levels of 100 percent, resulting in crop losses of 20 to 75 percent. LIYV was shown to have a wide plant host range of 45 species in 15 plant families. Disease symptoms include severe chlorosis and/or reddening, severe stunting, rolling, vein clearing and brittleness of leaves. The virus could not be transmitted mechanically. Single whiteflies had transmission efficiencies of 22 percent. The latent period of the virus in the insect was shown to be less than 6 hours; however, whiteflies lost their ability to transmit the virus in 3 days or less. Cotton, although not a host for the virus, does host the sweet potato whitefly, and provides breeding ground for a majority of the population. Other whitefly-transmitted viruses mentioned include beet pseudo-yellows and cucumber yellows virus (both transmitted by the greenhouse whitefly, *Trialeurodes vaporariorum*), Abutilon yellows and a yellow-vein-inducing virus of *Diodea* (both transmitted by *T. abutilonea*), and squash leaf-curl virus.

Macrosteles fascifrons has also been reported to transmit the oat dwarf virus. Migrating leafhoppers carry the virus from its overwintering habitat of Louisiana, Arkansas, Kansas and Missouri to barley fields in northern U.S. States. The virus is reported to overwinter in southern states in wheat and oats. In addition to viral crop damage, leafhoppers cause physical damage to crops from feeding activities. If plants are young when leafhoppers arrive, crop losses can reach 25 percent from all types of damage combined (SOLOMON 1986).

12 ORGANIC CONTROL OF ASTER YELLOWS

Most suggested control programmes for aster yellows include the use of insecticides to decrease vector populations. However, the use and effectiveness of insecticides will not be covered in this paper. Instead, other methods of control are discussed.

12.1 Mulches

In Florida, producers use aluminum mulching to repel aphids and reduce disease on tomatoes and peppers. CHAPMAN (1973) reported that aluminum foil mulching reduced populations of

M. fascifrons in lettuce significantly in some years. Effects were not significantly poorer than insecticide treatments in some years. In Minnesota, aluminum-coated paper reduced populations of *M. fascifrons* when compared to black polyethylene film and bare soil ZALOM (1981). Significant reductions in aster yellows were also effected. The percentage of aster yellows on lettuce was 0 to 9.1 percent with aluminum mulch, 5.5 to 38.5 percent with black plastic and 11.1 to 42.3 percent with bare soil. Also in Minnesota, aluminum foil was compared to oat straw mulch and conventional malathion spray program for carrots (SETIAWAN & RAGSDALE 1987). Early results were good: both aluminum and straw plots showed reduced populations of *M. fascifrons* over malathion-treated and control plots. However, by the beginning of August, no differences could be seen among the treatments. By the end of August when harvest occurred, the mulch and spray treatments had similar levels of aster yellows and all three had significantly lower disease incidence than the control. Crop canopy spread and dirt accumulation on mulch were cited as explanations for reduction in insect repellent efficiency as the season progressed. Overall, mulches equalled malathion in effectiveness as aster yellows controls. The percentage of aster yellows on carrots was 2.9 to 8.7 percent with aluminum mulch, 2.5 to 8.1 percent with oat straw, 2.1 to 11.2 percent with malathion and 4.8 to 14.6 percent in the control.

In Florida, aluminum foil and white polyethylene plastic soil mulches were tested against aphids which transmit watermelon mosaic virus (ADLERZ & EVERETT 1968). Aluminum foil mulch applied to all rows delayed infection by 5 and 20 days in separate tests. The growth of vines covered mulch surfaces; this may have reduced mulch effectiveness. The same mulches were tested on summer squash in California, again for aphids (WYMAN et al. 1979). Aluminum foil was the most effective, reducing migrating aphid populations by 96 percent. The only virus recovered was watermelon mosaic, and aluminum mulched plots had 94 percent less virus incidence than plots with bare soil. White plastic mulch was slightly less effective, reducing virus incidence by 77 percent.

12.2 Crop Covers

12.2.1 Shade Cloth

Plants that are in shade are less attractive to leafhoppers. Therefore, reduced feeding by leafhoppers reduces disease transmission (DOSHEIDT 1997).

12.2.2 Row Covers

Saran covered cages were used in Manitoba in the 1950's to demonstrate production of aster yellows-free lettuce that had been protected from the vector (LEE & ROBINSON 1958). In Bet Dagan, netted crop covers were tested on peppers, squash and potatoes to reduce aphid populations and, therefore, the incidence of aphid-vectored viruses (COHEN & MARCO 1979). In peppers, potato virus Y and cucumber mosaic virus (CMV) levels ranged from 35 to 100 percent in unprotected plots, while netted plots had nearly no infections. In one experiment on squash, netting reduced CMV levels by 32 percent, while in another test, only a slight delay in virus spread was seen. When virus-free tubers were used, potato leaf roll virus (PLRV) remained low (0 to 3%) under netting while uncovered plots had PLRV levels of 12 to 48 percent. However, when some of the tubers seeded were infected already, netted plots developed virus levels higher than control plots because of aphids trapped under the netting.

Sticky yellow polyethelene sheets were used to reduce PLRV levels in seed potatoes (ZIMMERMAN-GRIES 1979). Over two years, the virus incidence in treated plots ranged from 2 to 6 percent, while untreated plots had levels of 17 to 29 percent.

Spun-bonded polyester (SPB) floating row covers were tested in California to protect zucchini from the sweetpotato whitefly (*Bemisia tabaci*) and the viruses they transmit (NATWICK & DURAZO III 1985). SPB delayed virus symptoms until flowering compared to control plots, in which 12-day old seedlings showed symptoms. Yield of SPB-covered plots (369 cartons per acre) exceeded that of all other treatments, including plots sprayed with insecticides (18 cartons per acre in control plots, 25 to 153 cartons per acre with various insecticides). Upon removal of row covers, average whitefly counts on covered plants were 10 adults, while untreated check plants had 6,425 adults.

In Florida, SPB was again tested on zucchini, this time against both aphids and the sweet potato whitefly (WEBB & LINDA 1992). Covers excluded whiteflies and aphids, along with pickleworm and melonworm. When plants were uncovered, most insects took 2 weeks to reach high densities. However, the sweetpotato whitefly quickly spread to newly uncovered plants. The incidence of aphid-transmitted viruses and whitefly-transmitted silverleaf were reduced in covered plots. Virus symptoms did not appear until 1 to 2 weeks after cover removal.

PERRING et al. 1989 also tested floating row covers on cantaloupe in California, this time against both aphid- and whitefly-transmitted viruses. Reemay, Kimberly Farms Row Cover and Argyl covers were evaluated. All three delayed aphid feeding and aphid spring virus symptom onset by 2 weeks. Weed competition under row covers reduced yields from that of controls in the first year. In the second year, weeds were controlled and yields under row covers exceeded controls. In separate tests for the sweetpotato whitefly, virus incidence in covered plots was only 17.5 percent at the end of the season, compared with 95 percent in unprotected plots.

In the Netherlands, Agrifleece, Lutrasil LS10 and Rantai netting were tested to prevent aphid-transmitted viruses (potato virus Y, PVY and potato leafroll virus, PLRV) in seed potatoes (HARREWIJN et al. 1991). Only Lutrasil plots were 100 percent virus free, but Agrifleece and Rantai had a small proportion of infected plants. Virus levels in control plots reached up to 25 percent.

12.3 Fencing and Borders

CHAPMAN (1973) reports that in 1939, New Jersey researchers decreased lettuce infection by aster yellows from 32 percent to 1 percent by erecting 7 foot tobacco cloth fences around an area of 50 by 100 feet. This method was thought to be too costly and impeded irrigation. In addition, migrating leafhoppers descend from great altitudes. Thus, these fences may only be effective after migration has ceased.

In Wisconsin, borders of grains, corn or bare earth were used around plots. *M. fascifrons* moves only about 200 feet in 4 weeks once it enters a host crop. These movements are usually hops of 3 to 4 feet, at a height of less than 1 foot from the ground. Borders acted as barriers to leafhopper movement out of the plots, and disease incidence was concentrated at plot edges (CHAPMAN 1973). In areas outside of the path of migrating leafhoppers, planting larger fields takes advantage of the 'border effect' of aster yellows. This border effect results when non-migrating leafhoppers move into a crop from edges of the field. Aster yellows is then concentrated in the edges of the crop, decreasing in incidence towards the centre of the field. Infections from migrating leafhoppers display as overall general infections in a field, with no concentrated areas.

12.4 Breeding Resistance

HWANG et al. (1996) states that breeding for aster yellows resistance is the most promising control method, but that no resistant cultivars of specialty crops have yet been developed. In 1958, a breeding program was initiated to develop aster yellows resistant strains of flax following a severe epidemic in 1957 in Manitoba, Minnesota, North and South Dakota (MARTIN et al. 1961). Yields were reduced by 15 percent on average. A strain from the Abyssinian variety showed promising resistance although the mechanism could not be identified. Infected leafhoppers were caged with healthy plants from this strain, but few or no symptoms were observed. It is essential that the mechanism for resistance be identified because in the past, plants have been thought to be immune from the phytoplasma when in fact they merely did not express symptoms of the disease. In this breeding program, resistant strains were chosen on the basis of a lack of symptom expression. 'Resistant' plant tissues were not examined for the presence or absence phytoplasmas. It is possible that selection was not for resistance, but for symptomless carriers of the disease.

Symptom expression was also the method used to choose resistant lines of carrots in a breeding program started in 1982 in Wisconsin (GABELMAN et al. 1994). Selection was carried out until 1989. Breeders were again unable to determine the mechanism for aster yellows resistance, although reduced feeding was tentatively ruled out because plant preference among genotypes was not observed. Averaged over 3 years, 26 selected lines exhibited 2.5 to 35.3 percent infected plants per plot as opposed to 12 to 42 percent in 6 standard cultivars.

12.4.1 Plant Pubescence

Trichomes are the hairs arising from a plant's epidermis. Collectively, these hairs are referred to as pubescence. In breeding plant resistance to leafhoppers, the defensive properties of pubescence have been the most thoroughly studied. Two mechanisms have been proposed to account for this defence. First, the hairs act as a mechanical barrier to leafhoppers, preventing them from accessing preferred sites for feeding and oviposition. Secondly, trichomes interfere with leafhopper locomotion or actualiy trap the leafhoppers. Simple, hooked and secretory trichomes have been shown to confer resistance to leafhoppers in crop species (TINGEY 1985).

In cotton (*Gossypium* spp.), the density of simple, unbranched and stellate trichomes, plus trichome length were shown to increase resistance to leafhoppers. It is essential that abaxial midveins have trichome cover, and it is beneficial if abaxial leaf surfaces are also covered. The resistance mechanism is attributed to the hairs limiting leafhopper stylet access on major leaf veins, a preferred feeding site (mechanical barrier). Leafhoppers were a major pest of cotton in America until the development of two pubescent species, *G. hirsutum* and *G. basrbadense* (TINGEY 1985).

It was observed that soybean with curly or glabrous pubescence were less resistant to the potato leafhopper, *Empoasca fabae*, than plants with normal or dense pubescence. The major mechanism of defence is again that of a mechanical barrier. Leafhopper stylets are not long enough to reach through normal and dense hairs to the phloem in internal leaf tissues. Also, leafhoppers have difficulty landing and moving on the plant, and depositing eggs. This results in reduced oviposition, ingestion and growth of *E. fabae*. The nymphal stage took longer on plants with erect hairs and less nymphs completed development (TINGEY 1985).

Highly pubescent alfalfas also have better resistance to *E. fabae* than glabrous alfalfas. Exotic alfalfas have glandular trichomes which confer resistance to the potato leafhopper, alfalfa weevil (*Hypera postica*), pea aphid (*Acyrthosiphon pisum*) and alfalfa seed chalcid (*Bruchophagus roddi*). Nymph and adult leafhopper mortality were higher on pubescent species (TINGEY 1985).

Glandular trichomes are common in Solanaceae plants. These trichomes secrete phenolic compounds onto insects' bodies. These glue-like compounds then harden, affixing the insect to the leaf. Ninety-five percent of *E. fabae* nymphs die after 72 hours on the wild potato, *Solanum berthaultii*. Ninety percent of adults confined with only this plant for food starve to death rather than risk adhesion and immobility, which lead to death anyway. Breeders are currently using this wild species to develop cultivars with resistance to the potato leafhopper and green peach aphid (*Myzus persicae*). Other Solanacea species which have exhibited resistance to insects and mites are tomato, tobacco and petunia (TINGEY 1985).

Beans (*Phaseolus vulgaris*) have special hooked trichomes on stems, petioles, leaf surfaces and seed pods. Potato leafhopper nymphs become trapped and impaled by these hooks, and mortality

can exceed 60 percent. Nymphs which attempt to escape can lose appendages. Increased density of hooked trichomes results in greater nymph mortality (TINGEY 1985).

Field grown *Echinacea angustifolia* was observed to be more resistant to infection than *E. purpurea* in Alberta. HWANG et al. hypothesized that this resistance may be due to the more pubescent foliage of *E. angustifolia*.

12.4.2 Breeding Objectives

TINGEY (1985) lists the following as important when designing a breeding program for resistance of leafhoppers:

a) Start with a genetic diverse plant population;

b) Screening methods for rapid identification of resistant genotypes must be rapid;

c) Mechanisms which confer resistance must be identified and characterized according to their impact on pest biology;

d) Inheritance of resistance must be determined;

e) Use trap hosts and susceptible reservoir crops to optimize timing of infestations;

f) Utilizing multiple mechanisms for resistance may prevent the development of host-specific biotypes;

g) The mechanism(s) of leafhopper resistance should translate to reduced disease incidence.

12.5 Agronomic Practices

Agronomic practices are sometimes suggested as aids to cultural control. However, most recommendations of this nature are specific to annual crops. 'Control' for annual crops is meant in the sense that by delaying infection, producers can harvest the crop before disease symptoms appear and thus avoid reductions in saleability of the product. While a large portion of the crop may actually be infected with aster yellows, the crop is harvested within the window of symptom development. Unfortunately, a majority of specialty crop species are biennial or perennial and

subject to infection by leafhoppers over two or more seasons. With these crops, delaying symptom expression until harvest is not a valid approach in the control of aster yellows. Plants must be protected from infection until at least the season of harvest. Some of the following agronomic practices may reduce overall infection rates in biennial and perennial crops, but are likely not enough when considering the extended field life of these crops.

12.5.1 Seeding Methods

Late seeding of annual crops has been suggested to possibly reduce losses. CHANG et al. (1995) indicated that late seeding of pak-choi in Alberta could reduce disease incidence. In contrast, CHAPMAN (1973) indicates that in Manitoba, early maturing crops have lower infection rates than late maturing crops. Field-sown lettuce had high disease incidence, while lettuce from transplants could be harvested before vector populations reach maximums in August. Although at this time the percent of viruliferous leafhoppers has decreased, total population numbers counteract this reduction. Early maturing flax and early seeded flax also had lower incidences of aster yellows. However, high midsummer temperature (as explained in section 12.10) could explain why early maturing crops had lower disease incidence. CHAPMAN does note that in areas where migrant leafhoppers have the highest infectivity, delayed seeding reduces disease incidence.

Seeding rates could be increased so that infected plants could be rogued out while still leaving healthy plants at harvest (DOSHEIDT 1997). However, CHAPMAN (1973) reports that aster leafhopper populations and aster yellows disease incidence increase with plant density to a point. Fortunately, there is a threshold at which high plant density results in fewer leafhoppers and phytoplasma infections. This was shown in lettuce and flax. Ideal crop densities would vary with plant species.

12.5.2 Weed Control and Surrounding Crops

Leafhoppers are known to have a preference for weedy plant species. Weeds are also known to host the aster yellows phytoplasma. Weed control is essential in and around susceptible crops (DOSHEIDT 1997). In addition, the presence of forage legumes or other perennial crops in surrounding fields may increase disease incidence by providing phytoplasma inoculum and/or a source of leafhoppers (HWANG et al. 1996). In New York, weed control around lettuce crops

reduced the incidence of aster yellows. However, in the midwest, long distance migration of *Macrosteles fascifrons* offset any benefit of weed control around crops until after the migration subsided (PURCELL 1985). CHAPMAN (1973) reports that crops should be planted at least 200 feet from weedy areas. If impossible, crop placement should be upwind from these areas.

12.6 Biological Control

Several parasites of *M. fascifrons* have been identified. *Epigonatopus plesius* (Fenton) is a hymenopterous parasite of nymphs and adults in Ontario. *Pachygonatus minimus* (Fenton) parasitizes only *M. fascifrons*, and fall parasitization can reach as high as 37 percent of leafhopper populations in Manitoba. Spring levels are less than 1 percent. The female, wingless adult is also a predator of *M. fascifrons*. *Tomasvaryella sylvatica* (Meig.) can parasitize up to 25 percent of *M. fascifrons* in Manitoba, although it has also been found in Ontario. CHAPMAN (1973) did not consider control by parasites to be effective. However, some research in this field is promising. Researchers in California tested the spider, *Pardosa ramulosa*, as a predator of *M. fascifrons* in rice. Leafhopper populations were reduced to a maximum of 84 to 96 percent with densities of 22 spiders per square meter (ORAZE & GRIGARICK 1989).

12.7 Leafhopper Monitoring

Regular monitoring of leafhopper populations should aid producers in predicting aster yellows infection rates and levels of control measures required. Higher leafhopper populations generally imply higher infection rates. Many U.S. states base insecticide programs on leafhopper monitoring programs. An aster yellows index has been used in Wisconsin and Minnesota to aid growers with their spray programs. The index includes aster leafhopper density (total number of leafhoppers collected in 100 sweeps) and proportion of inoculative leafhoppers (determined in greenhouse tests). However, the results for the latter are not obtained until 2 or more weeks after sweep collections. PCR (polymerase chain reaction) detection of aster yellows in plants and leafhoppers has now been developed, and results take only 1 to 2 days (MURRAL et al. 1996).

12.8 Genetic Engineering

CHEN & CHEN (1998) suggest the future possibility of gene transfer to force plant immunity to aster yellows. It is hypothesized that the addition of antibody genes into plant DNA may

someday confer a plant immune response to phytoplasmas. Specific antibodies have already been discovered to inhibit the growth of mollicutes in the laboratory, and although plants are not naturally equipped with immune systems, technology could soon equip them.

12.9 Antibiotics

Antibiotics such as tetracycline have been used to protect high value plants, such as favoured trees, from phytoplasma infection. However, the cost is high and is not practical in field situations (HWANG et al. 1996). KIRKPATRICK (1989) indicates that tetracycline only reduces disease symptoms in infected plants. Therefore, treatment must be continual. Leafhopper transmission efficiency was also reduced by injection of tetracycline, but this effect was also short-lived. Penicillin was not an effective treatment for plant disease symptoms. The over-use of antibiotics is well publicized as of late; field use of antibiotics may contribute to the development of further antibiotic resistance.

12.10 Heat

KUNKEL (1937) states that aster yellows is not prominent in the southern United States because of seasonally high temperatures. It was shown that heat reduces the ability of *M. fascifrons* to transmit aster yellows. In fact, depending on the length of time leafhoppers were exposed to temperatures of 31 to 32°C, and whether leafhoppers were fully inoculative or in the latent period, leafhoppers either temporarily lost the ability to transmit aster yellows, or lost the ability permanently. Leafhoppers exposed to these temperatures for at least 12 days lost transmission ability permanently. PURCELL (1985) also reports that during the summer in Florida, greenhouse studies on aster yellows transmission were curtailed by extreme heat.

In the Netherlands, gladiola corms and hyacinth bulbs are treated with hot water at 50°C for 1 hour to cure them of aster yellows spread by the European leafhopper, *Macrosteles sexnotatus*. Best results were on bulbs stored at 9°C before and after treatment. Only one of three gladiola cultivars had a reduction in yield with this treatment (SLOGTEREN et al. 1974). In separate tests, water at 53 to 55°C for 30 minutes also cured infected corms, but the 50°C, 1 hour treatment was still the most effective, especially when given between mid-December and mid-January. Corms were best stored at 3 to 9°C before treatment and 13 to 17°C after

treatment. An extended treatment of 38°C for 4 weeks was also effective (GROEN & SLOGTEREN 1974).

Thermotherapy was conducted on periwinkle infected with the safflower phyllody phytoplasma in Israel (ZELCER et al. 1972). Electron microscopy of tissue revealed degradation of phytoplasma bodies in plants held at 40°C compared to normal phytoplasmas in plants held at 25°C. Degraded phytoplasmas were almost devoid of internal structure and some had ruptured membranes. These effects peaked at 7 days and remained unchanged for a further 43 days when tests ended. It would be interesting to see if phytoplasmas would regenerate after lower temperatures were restored.

12.11 Sanitation

Sanitation is one of the most important methods of control, regardless of whether insecticides are used or not. Infected plants provide inoculum for leafhoppers, and even a few stray leafhoppers feeding on one infected plant can potentially spread aster yellows to many more plants. Many leafhopper vectors have been reported to survive better on aster yellows-infected plants than healthy plants. PURCEL (1985) even reports that insects unable to transmit aster yellows can survive longer on plants infected with the phytoplasma. Although this phenomenon has yet to be explained, infected plants seem to be more conducive to leafhopper survival, and may even be more attractive than healthy plants. Roguing (the removal of diseased plants) is very important to reduce inoculum and prevent further infections.

CHAPMAN (1973) reports a conflicting view on roguing. Although roguing was shown to decrease aster yellows incidence in lettuce up to 50 percent, this method was not as effective as insecticide use. One study even showed slightly increased aster yellows incidence following roguing. It was thought that infected leafhoppers disturbed from rogued plants moved to healthy plants, therefore spreading the infection more than if plants had been left undisturbed. CHAPMAN concludes that although roguing is definitely effective for other plant pathogens, it has little value for controlling aster yellows.

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